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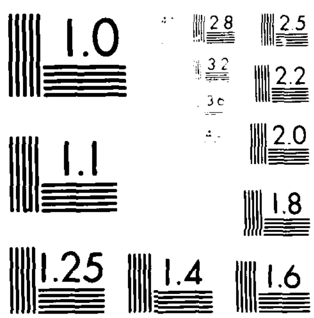

MICROCOPY RESOLUTION TEST CHART

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this effort was to determine the requirements, configuration and cost for a standard Crash Survivable Flight Data Recorder (CSFDR) for fighter, attack and trainer aircraft. An additional objective was the determination of broader usage of a standard configuration for the tri-services along with expansion of the system to include maintenance monitoring functions.

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Block 20: ABSTRACT (Continued)

A standard system identified using the F15, F16 and A10 aircraft has typical applications. Common signal conditioning, processing, data memory size, system crash survivability and configuration are determined. A life cycle cost analysis was prepared using the A10 fleet as a typical application.

The study concluded that a single CSFDR design employing a single electronics unit with an attached survivable memory module located mid-fuselage is the most cost effective way to implement a flight data recorder. Record module survivability designed to current FAA transport category requirements with extended fire protection is recommended. The CSFDR unit defined is a completely solid-state device less than six inches cubed, weighing 9.5 pounds with a reliability estimated to be 10,000 hours.

The study also concludes that a similar configuration applicable to a wide range of small fixed and rotary wing aircraft is feasible providing the increased fly-a-way cost overhead is offset by the economies of a single tri-service design.

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REQUIREMENTS, TECHNOLOGY AND CONFIGURATION EVALUATION FOR CRASH SURVIVABLE FLIGHT DATA RECORDING (CSFDR)SYSTEM

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CONTENTS

A

ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

CSFDR

SUMMARY

This report concludes that a small, low cost, solid-state flight data recording system can be defined and developed in the near term that would be a common inventory item on typical fighter and attack aircraft such as the F15, F16 and A10. This document recommends that the development of such a device be undertaken for this class of aircraft and that a similar requirements study to that reported herein be undertaken for large multi-engine aircraft.

The study conduct included a review of Air Force mishap data in conjunction with the Air Force Inspection and Safety Center (AFISC) and the development of a prioritized set of candidate parameters for recording. Based on these parameters, the composite signal conditioning requirements were generated using airframe signal source information on the F15, F16 and A10. In addition, installation tradeoff studies on these typical aircraft were undertaken along with a review of flight data recorder crash survivability using current FAA transport category requirements as a reference point. Airborne memory size requirements were also studied.

A single box concept was selected and placed in a mid-fuselage location based primarily on lowest life cycle cost and the difficulty of placing a separate survivable recorder module in the remote and environmentally hostile tail section of high performance supersonic aircraft.

Expansion of the selected baseline system was studied for broader tri-service application along with emphasis on future aircraft and Air Force transports and bombers. Essentially the same concept was identified for future aircraft of this type except that the system would be simplified due to the expected universal application of a general purpose avionics data bus structure. The chosen concept was judged to be a candidate for tri-service application for small fixed and rotary wing aircraft on a selected basis depending on mission and crew size. Flight recorder expansion in consideration of maintenance monitoring functions was also studied in the areas of engine health, airframe structural integrity and flight controls. It was concluded that these additional functions could economically benefit by taking advantage of the flight recorder signal conditioning and data storage capability applied to current generation aircraft.

Ground software and ground support equipment needs were identified for the baseline and expanded systems.

A life cycle cost analysis was prepared using the current planned A10 fleet as an example. A sensitivity analysis was conducted using a computer model to determine the bottom line effects on life cycle cost due to such prime factors such as system fly-away cost, reliability, and repair cost. The sensitivity analysis results were used to estimate the principle effects on life cycle cost due to possible future system improvements and expansion as described above.

A benefit analysis summary was prepared using data and expert opinions obtained from AFISC and other agencies. The major benefit factor is estimated to be the reduction in repeat major mishaps. Using the A10 fleet as an example, it is estimated that at least 0.5 aircraft per year reduction in attrition rate will be evidenced due to more accurate and timely cause resolution.

The attributes of a standard crash survivable flight data recording system for fighter, attack and trainer aircraft for 1982 application are estimated as follows:

* Flight data recorder unit
    * 177 cubic inches
      (Approx. 6 X 6 X 5 inches)
    * 9.5 pounds
    * 10,000 hrs MTBF
* System (using the A10 fleet as typical)
    * 4 added sensors
    * 20.5 pounds total installed weight
    * 7,120 hrs MTBF
* Cost in 1980 dollars (using the A10 fleet of 717 aircraft)
    * Fly-away per aircraft (Retrofit)
        * 18,500 dollars
    * Life cycle - 20 years
        * 18,300,000 dollars

1.0 INTRODUCTION

This report documents the results of engineering effort performed by Hamilton Standard under contract number F33615-80-E-0134. The effort also included engineering support from McDonnell Douglas, St Louis, Missouri on the F15, General Dynamics, Fort Worth, Texas on the F16 and Fairchild Republic Farmingdale, Long Island, New York on the A10 aircraft.

The above respective airframe companies provided valuable assistance in establishing the candidate parameter list, the detail signal characteristics relating to the parameters, installation factors and tradeoff support as well as assistance in the determination of life cycle costs.

The effort was conducted in three major phases.

I Conceptual Analysis For Basic Crash Survivable Flight Data Recorders

II Basic System Expansion

III Life Cycle Cost Analysis

The results of Phases I and II were discussed with cognizant Air Force personnel at the completion of each of these elements in order that the benefits of an ongoing engineering interchange be reflected in the completed effort. In addition to the Phase I and II briefings, two (2) visits were made to the Air Force Inspection and Safety Center to obtain data and expert opinion on mishaps and the potential utility of flight recorders to augment mishap investigation. Several visits were also made to the airframe and engine manufacturers along with numerous contacts with other government agencies concerning mishap data and flight data recorder utility.

2.0 TRADEOFFS AND STANDARD SYSTEM DESCRIPTION

Using the results of the parameter analysis, the installation and survivability studies and hardware/software definition, further tradeoffs are conducted to determine the basic system architecture. From the chosen architecture recommended standard (Basic) CSFDR definitions are provided for near term and far term application to fighter, attack and trainer aircraft as follows.

2.1 PARAMETER ANALYSIS AND PRIORITIZATION

Hamilton Standard, in conjunction with the Air Force Inspection and Safety Center (AFISC), conducted an in-depth study of fighter/attack aircraft mishaps which have occurred over the last four (4) years in an effort to establish aircraft crash survivabiltiy requirements for the CSFDR and crash investigation utility factors associated with parameters in crash investigation cause determination. This study was directed to the A10, F15 and F16 aircraft application and mishaps involving these aircraft which have occurred to date. Thirty-five (35) Class A accidents involving A10, F15 and F16 aircraft were studied in detail.

There were seventeen (17) A10, thirteen (13) F15 and five (5) F16 aircraft mishaps. Each parameter in the Air Force statement of need (SON) dated 27 August 1979 plus AFISC suggested parameter additions were evaluated in relation to each mishap to determine if the parameter would have been of significant value in the investigation of that particular mishap. Each parameter was then averaged to obtain an AFISC utilization factor. The results of this determination are summarized in Tables 1 through 4 and includes the maximum utilization percentage for each parameter as relates to each aircraft type.

The prioritization was based on considering a particular parameter independent of interrelated parameters. Instances exist in which the importance of a particular parameter may be reduced if the interrelated parameter(s) are available. This results in increased utilization which shows up in the secondary parameter list. The following parameters are considered to have higher utilization factors than would be afforded if the other parameters were not taken into account:

1. Mach Number - Derivable from Altimeter and Airspeed.

2. Stick and Rudder Pedal Positions - With known surface position, these parameters have reduced utility.

A reduction in utility factor of 50% is felt to be in order for these parameters.

Flap and slat position are of increased importance on the A10 aircraft and after-burner position is of increased importance on the F15 and F16. Provision for handling these type of aircraft dependent parameters is incorporated in the CSFDR concept presented herein.

TABLE 1. AIR FORCE BASELINE PARAMETER LIST (PRIORITIZED)

PARAMETERS	AFISC COMPOSITE UTILIZATION FACTOR IN MISHAP INVESTIGATIONS	HIGHEST UTILIZATION FACTOR / AIRCRAFT
AIRFRAME		
CALIBRATED AIRSPEED	57%	77% / F15
ALTITUDE (BAROMETRIC)	54%	69% / F15
SINK RATE (VERTICAL VELOCITY)	0% (DERIVABLE FROM ALTITUDE)	
PITCH ATTITUDE	51.4%	65% / A10
PITCH RATE	2.9% (DERIVABLE FROM PITCH ATTITUDE)	20% / F16
BANK ANGLE (ROLL ATTITUDE)	46.9%	65% / A10
ROLL RATE	2.9% (DERIVABLE FROM ROLL ATTITUDE)	20% / F16 (NOT A FACTOR IN A10 AND F15)
NORMAL LOAD FACTOR (VERTICAL G'S)	42.7%	47% / A10
HEADING	11.6%	20% / F16
YAW RATE	40.2% (DERIVABLE FROM HEADING)	71% / A10
ANGLE OF ATTACK	37%	59% / A10
SIDE SLIP ANGLE	2.9%	20%/F16 (NOT A FACTOR IN A10, F15)
PRIMARY FLIGHT CONTROLS		
RUDDER POSITION	43.1%	65%/A10/(NOT A FACTOR IN F16)
ELEVATOR POSITION	42.9%	54%/F15 (NOT A FACTOR IN F16)
AILERON POSITION	42.8%	59%/A10 (NOT A FACTOR IN F16)

TABLE 2. AIR FORCE BASELINE PARAMETER LIST (CONTINUED)

(PRIORITIZED)

PARAMETERS	AFISC COMPOSITE UTILIZATION FACTOR IN MISHAP INVESTIGATIONS	HIGHEST UTILIZATION FACTOR / AIRCRAFT
<u>ENGINE RELATED</u>		
ENGINE RPM (N1)	57.3%	62% / F15
ENGINE FUEL FLOW	48.7%	80% / F16
ENGINE RPM (N2)	48.4%	80% / F16
ENGINE EGT	42.9%	60% / F16
THROTTLE POSITION	34.2%	60% / F16
FUEL QUANTITY (TOTAL)	22.9%	60% / F16
OIL PRESSURE	17.5%	24% / A10
<u>ELECTRICAL SYSTEMS</u>		
GENERATOR OUTPUTS	14.6% (NOT A FACTOR	24% / A10
INVERTER OUTPUTS	8.7% IN F15 & F16)	18% / A10
<u>HYDRAULIC SYSTEMS</u>		
HYDRAULIC PRESSURE	45.8%	53%/A10 AND F15
UTILITY HYDRAULIC PRESSURE	19.7%	29% / A10
OTHER		
MASTER CAUTION	58.5%	

TABLE 3. AIR FORCE SECONDARY PARAMETER LIST

(PRIORITIZED)

PARAMETERS	AFISC COMPOSITE UTILIZATION FACTOR IN MISHAP INVESTIGATIONS	HIGHEST UTILITY FACTOR / AIRCRAFT
AIRFRAME		
MACH NUMBER	14.6%	20% / F15
SIDESLIP ANGLE	2.9%	20% / F16 (NOT A FACTOR IN A 10 & F15)
LANDING GEAR POSITION	0 %	
FLIGHT CONTROLS		
STICK POSITION OR FORCE	42.8%	53% / A10 (NOT A FACTOR IN F16)
SLAT POSITION (A10 ONLY)	31.6%	65%/A10 (NOT A FACTOR IN F15 & F16)
CAS PITCH	31.1%	38% / F15
RUDDER PEDAL POSITION OR	28.5%	35 % / A10
FORCE		35% / A10
TRIM (ALL AXES)	28.4%	47% / A10 (NOT A FACTOR IN F16)
SPEED BRAKE POSITION	22.8%	18% / A10 (NOT A FACTOR IN F15 & F16)
FLAP POSITION	8.7%	6% / A10 (NOT A FACTOR IN F15 & F16)
STABILITY AUGMENTATION SYSTEM (SAS)	2.9%	

TABLE 4. AIR FORCE SECONDARY PARAMETER LIST (CONTINUED)

(PRIORITIZED)

PARAMETERS	AFISC COMPOSITE UTILIZATION FACTOR IN MISHAP INVESTIGATIONS	HIGHEST UTILIZATION FACTOR / AIRCRAFT
AVIONICS		
AIR DATA COMPUTER (ADC) STATUS	5.6%	15% / F15 (NOT A FACTOR IN A10 & F16)
FIRE CONTROL SYSTEM (FCC) STATUS	.0%	
ENGINE RELATED		
FIRE WARNING	20.2%	31%/F15
FUEL QUANTITY (PER TANK)	17.2%	40% / F16
FAN TURBINE INLET TEMPERATURE (FTIT)	17.1%	46% / F15 (NOT A FACTOR IN A10 & F16)
AFTERBURNER (A / B) POSITION	11.4%	23% / F15 (NOT APPLICABLE TO A10)
STARTER	2.9%	23% / F15 (NOT A FACTOR IN A10 & F16)
OIL QUANTITY	.0%	
OTHER		
EPU / APU	8.8%	12% / A10(NOT A FACTOR IN F16)
PADDLE SWITCH	8.7%	18% / A10(NOT A FACTOR IN F15 & F16)
COMMUNICATIONS TRANSMIT	5.8%	12% / A10(NOT A FACTOR IN F15 & F16)
OUTSIDE AIR TEMPERATURE (OAT)	5.6%	15% / F15(NOT A FACTOR IN A10 & F16)

Hamilton Standard compiled a list of parameters based on the Air Force contract requirements and included additions which Hamilton Standard and Air Force Inspection and Safety Center experience indicated would be useful in mishap investigations.

Hamilton Standard conducted meetings with the airframe manufacturers (A10 -Fairchild Republic, F15 - McDonnel Douglas, F16 - General Dynamics) to determine the availability of the parameters on production aircraft and the most economical method of interfacing with the available signals. In instances where parameters were not available on the aircraft, alternate means of obtaining the parameters or their nearest equivalents were evaluated. Alternate means considered included deriving the signals from existing signal sources, using an alternate parameter which provides suitable substitute information and addition of signal sources.

Additional parameters were included as a result of discussions with the airframe manufacturers. Most of these added parameters were discretes and all were oriented to the specific airframe.

The candidate parameters available plus evaluated additions for the A10, F15 and F16 are defined in Tables 5 through 12 (A10), Tables 13 through 21 (F15) and Tables 22 through 33 (F16).

The parameter source selection recommendations are based on providing the required parameters at minimum installed cost. Since installation costs are a major part of the overall cost, they are weighted heavily in selection where multiple sources are available. For instance, MIL-STD-1553 Digital Data Bus signals are preferred when they are available since this minimizes the wiring required to interface with a large number of parameters. Non data bus signals are selected based on availability and commonality between airframes.

The Air Force primary and secondary parameter lists were grouped into Airframe Flight Control, Engine, Electrical System, Hydraulic System and other categories and are shown in Tables 34 through 40.

Primary Parameters

Primary Flight Control Surface sensors are not standard on any of the aircraft. The A10 and F15 require installation of sensors on aircraft not equipped with structural integrity system sensors. The engineering to incorporate the sensors has been done for the structural monitoring program and aircraft with installed structural monitoring systems have the required sensors.

The F15 has a unique parameter in the elevator linkage ratio which controls the elevator control authority.

On the F16, stick input sensors are installed and provide information which can be related to the control surface positions. The F16 also has the structural monitoring sensor installations designed and incorporated in structural monitoring system equipped aircraft. The stick input sensors were selected for the F15

TABLE 5. A10 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPUNSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Load Factor (Counting Accelerometer)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	
Angle of Attack	5^0 to 19^0	11.8 VRMS 400 Hz	TBD	$\pm$ $1/2^0$	NA	TBD	100K	Synchro - high null. From AOA Transmitter
Rudder Position	$\pm$ 25^0	0 to 10 VDC	0.200 VDC/DEG	TBD	NA	10K	100K	No sensors exist on A/C.
Elevator Position	-10^0 to + 35^0	0 to 10 VDC	0.222 VDC/DEG	TBD	NA	10K	100K	No sensors exist on A/C.
Aileron Position	-21^0 to $+28^0$	0 to 10 VDC	0.204 VDC/DEG	TBD	NA	10K	100K	No sensors exist on A/C.
Left Engine RPM (N_C)	0 to 100%	0 to 4200RPM 0-14.7VPK	42 RPM = 1%	TBD	NA	$\leq$ 200	100K	
Right Engine RPM (N_C)	0 to 100%	0 to 4200RPM 0-14.7VPK	42 RPM = 1%	TBD	NA	$\leq$ 200	100K	
Left Engine RPM (N_F)	0 to 100%	0 to 3666Hz 0 to 5 VPK	36.66 Hz = 1%	TBD	NA	$\leq$ 200	100K	

TABLE 6. A10 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Right Engine RPM (N_F)	0 to 100%	0 to 3666Hz 0 to 5 VPK	36.66 Hz = 1%	TBD	NA	200	100K	
Left Engine Fuel Flow Rate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Magnesyn - Indicator converts second harmonic signal from transmitter
Right Engine Fuel Flow Rate	TBD	TBD	TBD	TBD	TBD	TBD	TBD	
Fuel Quantity	0 to 12,240 *Pounds*	0 to 10 VDC	0.8 MVDC/Lb	TBD	NA	5K	100K	VGH provides excitation *in only 1 of 10 A/C*
Left Power Lever Angle (PLA)	0 to 100%	0 to 10 VDC	0.1 VDC = 1%	TBD	NA	10K	100K	Sensor is installed in every other A/C
Right Power Lever Angle (PLA)	0 to 100%	0 to 10 VDC	0.1 VDC = 1%	TBD	NA	10K	100K	No sensor exists in A/C.
Right Speed Brake (SB)	Lower = 66 $\pm$ 3° Upper = 78 $\pm$ 5°	TBD	TBD	TBD	TBD	TBD	TBD	SAS LVDT sensor is installed in every A/C. SAS provides excitation

TABLE 7. A10 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Rudder Limiting	25^0 8^0	0 VDC 28 VDC	NA	20K Max.	1 Meg	J3-A or J3-C (FCRB)	Goes from 25^0 to 8^0 at 240 knots. Flight Control Relay Box (FCRB)
Elevator Disengage	Engaged Disengaged	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-NN (AP)	Annunciator Panel (AP)
Left Elevator Jam Light	Normal Fault	0 VDC 28 VDC	4 Seconds Min.	20K Max.	1 Meg	J1-G (AP)	Voltage remains on for four (4) seconds after jam leaves.
Right Elevator Jam Light	Normal Fault	0 VDC 28 VDC	4 Seconds Min.	20K Max.	1 Meg	J2-N (AP)	
Aileron *Disengage*	Engaged Disengaged	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-MM (AP)	Uncouples left or right aileron from linkage during a jam
Left Aileron Tab Warning Light	Normal Fault	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-DD (AP)	
Right Aileron Tab Warning Light	Normal Fault	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-r (AP)	
Left Aileron Tab Shifter Switch	Normal Manual	0 VDC 28 VDC	NA	20K Max.	1 Meg	J2-V (FCRB)	
Right Aileron Tab Shifter Switch	Normal Manual	0 VDC 28 VDC	NA	20K Max.	1 Meg.	J2-Y (FCRB)	

TABLE 8. A10 DISCRETE SIGNALS

PARAMETERS	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Left Aileron Jam Light	Normal Fault	0 VDC 28 VDC	4 Seconds Min.	20K Max.	1 Meg	J1-d (AP)	Voltage remains on for four (4) seconds after jam leaves.
Right Aileron Jam Light	Normal Fault	0 VDC 28 VDC	4 Seconds Min.	20K Max.	1 Meg	J2-M (AP)	
Left Engine Fuel Pressure	Normal Low	Open Gnd.	NA	10K Max.	1 Meg	J1-x (AP)	
Right Engine Fuel Pressure	Normal Low	Open Gnd	NA	10K Max.	1 Meg	J1-j (AP)	
Left Engine Hot	Normal Overtemp	Open Gnd	NA	10K Max.	1 Meg	J1-CC	Overtemp = 860°C
Right Engine Hot	Normal Overtemp	Open Gnd	NA	10K Max.	1 Meg	J1-q (AP)	Overtemp = 860°C
Left Engine Oil Pressure	Normal Low	Open Gnd	NA	10K Max.	1 Meg	J1-BB (AP)	Low pressure = 1900 psid
Right Engine Oil Pressure	Normal Low	Open Gnd	NA	10K Max.	1 Meg	J1-p (AP)	Low pressure = 1900 psid
Left Engine Generator	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-v (AP)	

TABLE 9. A10 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Right Engine Generator	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-h (AP)	
Left Engine DC Converter	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-w (AP)	
Right Engine DC Converter	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-i (AP)	
Instrument Inverter	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-K (AP)	
Left Engine Hydraulic Pressure (P1)	Normal Low	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-GG (AP)	
Right Engine Hydraulic Pressure (P2)	Normal Low	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-u (AP)	
Left Hydraulic System Shutoff Valve	Open Closed	0 VDC 28 VDC	NA	20K Max.	1 Meg	J2-c (FCRB)	
Right Hydraulic System Shutoff Valve	Open Closed	0 VDC 28 VDC	NA	20K Max.	1 Meg	J2-C (FCRB)	
Landing Gear Down	Not Down Down	0 VDC	NA	20K Max.	1 Meg	J1-x	Down is down and locked. Pickup at Landing Gear Control Panel.

TABLE 10. A10 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Slat	In Out	28 VDC 0 VDC	NA	20K Max.	1 Meg	J1-N	From ALPHA Mach Computer
7^{o} Manuevering Flap Position	7^{o} Not 7^{o}	28 VDC 0 VDC	NA	20K Max	1 Meg	J3-. (FCRB)	0^{o} Flap position is assumed if not in full flap position or 7^{o} flap position
Full Flap Position	Full Not Full	28 VDC 0 VDC	NA	20K Max	1 Meg	J3-T (FCRB)	
Pitch SAS	In Out	Open Gnd	NA	10K Max	1 Meg	J1-LL (AP)	
Yaw SAS	In Out	Open Gnd	NA	10K Max.	1 Meg	J1-KK (AP)	
Horizontal Attitude Reference System (HARS)	Normal Fault	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-E (AP)	
Inertial Navigation System (INS) Fault	Normal Fault	Open Gnd	NA	10K Max	1 Meg	J1-L (AP)	
Central Air Data Computer (CADC) Fault	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-K (AP)	
Alpha Mach Computer Fault	Normal Fault	Open Gnd	NA	10K Max.	1 Meg	J1-P (AP)	
Gun Fire	Not Firing Firing	0 VDC 28 VDC	NA	20K Max.	1 Meg	J2-B (FCRB)	Signal from gun trigger

TABLE 11. A10 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	SOURCE RESPONSE TIME	SUGGESTED IMPEDANCE (IN OHMS)	MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Left Engine Fire	No Fire Fire	0 VDC 28 VDC	NA	20K Max.	1 Meg	Pin-B	Left engine fire detector
Right Engine Fire	No Fire Fire	0 VDC 28 VDC	NA	20K Max.	1 Meg	Pin-B	Right engine fire detector
APU Fire Warning	No Fire Fire	0 VDC 28 VDC	NA	20K Max.	1 Meg	Pin-B	APU fire detector
Canopy	Open Closed	28 VDC 0 VDC	NA	20K Max.	1 Meg	Canopy Lock Switch	
Stall Warning	Normal Stall	0 VDC 28 VDC	NA	20K Max.	1 Meg	J1-L	From ALPHA Mach Computer Connects to tone generator in pilot's headset.
GRU/MRU Discrete	Off On	Open Gnd	NA	TBD	TBD	--	Sets CSFDR in mode for data retrieval/readout and system test
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	

TABLE 12. A10 DIGITAL SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	BLOCK/ WORD	TRANSMISSION RATE	REMARKS
Mach Number	0.1 to 0.8 Mach	14 Bits + Sign	Bit (15)=0.00024M Bit(2)=2M Bit(1)=Sign	C01/05	25/Sec	Source is CADC
True Airspeed	70 to 600 Knots	15 Bits + Sign	Bit (15)=.125Kts Bit (2) =1024Kts Bit (1)=Sign	C02/04	25/Sec	Source is CADC
Barometric Altitude	-1000 to 45,000 Ft	16 Bits + Sign	Bit (16)=2.5Ft Bit (2)=40,960Ft Bit (1)=Sign	C02/03	25/Sec	Source is CADC
Pitch Attitude	$-\pi$ to π Radians	14 Bits + Sign	Bit(14)=π/8192Rad. Bit(2)$\approx$ π/2Rad. Bit(1)=Sign	I04/11	50/Sec	Source is INU
Roll Attitude	$-\pi$ to π Radians	14 Bits + Sign	Bit(14)=π/8192Rad. Bit(2)=π/2Rad. Bit(1)= Sign	I04/10	50/Sec	Source is INU
Heading	$-\pi$ to π Radians	14 Bits + Sign	Bit(14)=π/8192Rad. Bit(2)= π/2Rad. Bit(1)=Sign	I04/12	50/Sec	Source is INU

TABLE 13. F15 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Left Rudder Position	Out of Phase 0o to -30^{0}	8.01 VRMS, 400 Hz	0.267 VRMS/DEG Rotation from Null	± 1%	NA	200 + j690	≥100K	Sensor installed on only one out of every five A/C for ASEPS.
Right Rudder Position	In Phase 0^{0} to +30o	8.01 VRMS, 400 Hz	0.267 VRMS/DEG Rotation from Null	± 1%	NA	200 + j690	≥100K	Must add sensor, already engineered in.
Left Stabilator Position	+15^{0} to -29^{0}	±6.224 VDC	0.283 VDC/DEG	±5%	NA	≤200	≥100K	
Right Stabilator Position	+15^{0} to -29^{0}	±6.224 VDC	0.283 VDC/DEG	± 5%	NA	≤200	≥100K	
Left Aileron Position	Out of Phase 0^{0} to -20^{0}	5.34 VRMS, 400 Hz	0.267 VRMS/DEG Rotation from Null	± 1%	NA	200 + j690	≥100K	Sensor installed on only one out of every five A/C for ASEPS.
Right Aileron Position	In Phase 0^{0} to +20^{0}	5.34 VRMS, 400 Hz	0.267 VRMS/DEG Rotation from Null	± 1%	NA	≤200 + j690	≥100K	Sensor installed on only one out of every five A/C for ASEPS.
Left Engine Speed (N1)	8,000 to 15,000 RPM	1,900 to 9,500 Hz	0.633 Hz/RPM	TBD	NA	≤200	≥100K	
Right Engine Speed (N1)	8,000 to 15,000 RPM	1,900 to 9,500 Hz	0.633 Hz/RPM	TBD	NA	≤200	≥100K	
Left Engine Speed (N2)	1,320 to 15,100 RPM	198 to 2,265 Hz	0.15 Hz/RPM	TBD	NA	≤200	≥100K	

TABLE 14. F15 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Right Engine Speed (N2)	1,320 to 15,100 RPM	198 to 2,265 Hz	0.15 Hz/RPM	TBD	NA	$\leq$ 200	$\geq$ 100K	
Left Power Lever Angle (PLA)	0^{o} to 55.68^{o}	400 Hz	TBD	TBD	NA	TBD	$\geq$ 100K	Synchro excitation is 26 VRMS 400 Hz.
Right Power Lever Angle (PLA)	0^{o} to 55.68^{o}	400 Hz	TBD	TBD	NA	TBD	$\geq$ 100K	Synchro excitation is 26 VRMS, 400 Hz.
Left Afterburner Nozzle Position	0 to 100%	VRMS, 400 Hz	0%=55.2^{o} 100%=295.2^{o}	$\pm 2.4^{o}$	NA	TBD	$\geq$100K	Excitation for synchro is 26 VRMS, 400 Hz
Right Afterburner Nozzle Position	0 to 100%	VRMS, 400 Hz	0%=55.2^{o} 100%=295.2^{o}	$\pm 2.4^{o}$	NA	TBD	$\geq$100K	Excitation for synchro is 26 VRMS, 400 Hz

TABLE 15. F15 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Rudder Limiting	Normal Fault	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	Rudder limiter not scheduling properly Caution Light Panel (CLP)
Left and Right Boost Pump Pressure	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Fuel Hot	Normal Overtemp	0 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	Engine fuel inlet temperature high.
Left Electronic Engine Control (EEC)	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Right Electronic Engine Control (EEC)	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Left Engine Overtemp (FTIT)	Normal Hot	0 VDC 28 VDC	NA	≤ 50	20K	Left Engine Interface	
Right Engine Overtemp (FTIT)	Normal Hot	0 VDC 28 VDC	NA	≤ 50	20K	Right Engine Interface	
Left Bleed Air Leak/Temperature	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	Left bleed air leak or overtemp.
Right Bleed Air Leak/Temperature	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	Right bleed air leak or overtemp

TABLE 16. F15 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Inlet Ice	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	Ice buildup in left inlet.
Left Engine Oil Pressure	Normal Low	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Right Engine Oil Pressure	Normal Low	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Left AC Generator Out	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Right AC Generator Out	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Left Bus DC Generator	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Right Bus DC Generator	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Emergency DC Bus	Normal Abnormal	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (CLP)	
Left Hydraulic Pressure(PCIA)	Normal Low	0 VDC 28 VDC	NA	≤ 200	56K	Front Cockpit (Bit Panel)	

TABLE 17. F15 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Left Hydraulic Pressure (PC2A)	Normal Low	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Right Hydraulic Pressure (PC1B and PC2B)	Normal Low	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Left Pump	Normal Fault	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Right Pump	Normal Fault	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Utility Hydraulic Pressure A	Normal Low	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Utility Hydraulic Pressure B	Normal Low	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (Bit Panel)	
Weight On Wheels (WOW)	Retracted Extended	0 VDC 28 VDC	NA	$\leq$ 1K	1 Meg	Front Cockpit (CLP)	MIL-STD-704 - (provide overvoltage protection)
CAS Roll	On Off	0 VDC 28 VDC	NA	$\leq$ 6K	$\geq$ 100K	Front Cockpit (CLP)	CAS inoperative or disengaged
CAS Pitch	On Off	0 VDC 28 VDC	NA	$\leq$ 6K	$\geq$ 100K	Front Cockpit (CLP)	CAS inoperative or disengaged

TABLE 18. F15 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
CAS YAW	On Off	0 VDC 28 VDC	NA	$\leq$ 6K	$\geq$ 100K	Front Cockpit (CLP)	CAS inoperative or disengaged
Speed Brake Position	Out (45^{o}) Not Out (0^{o})	0 VDC 28 VDC	NA	$\leq$ 10	56K	Front Cockpit (CLP)	
Flap Position	Out (30^{o}) Not Out (0^{o})	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit	Indication of flaps in transit or flaps down
Air Data Computer (ADC) Status	Fail Go	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (CLP)	
Central Computer (CC) Status	Fail Go	0 VDC 28 VDC	NA	$\leq$ 10	56K	Front Cockpit (CLP)	
Left Engine Fire Warning	No Fire Fire	0 VDC 28 VDC	75 MSEC MIN	$\leq$ 1K	50K	Front Cockpit (CLP)	
Right Engine Fire Warning	No Fire Fire	0 VDC 28 VDC	75 MSEC MIN	$\leq$ 1K	50K	Front Cockpit (CLP)	
Canopy Lock/ Unlock	Lock Unlock	Open Closed	NA	$\leq$ 50	10 MEG	Front Cockpit (CLP)	Switch contacts
Hook	In Out	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (CLP)	Hook unlocked

TABLE 19. F15 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Anti-Skid	Normal Fault	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (CLP)	Anti-skid inoperative or off
Oxygen Low	Normal Low	0 VDC 28 VDC	NA	$\leq$ 200	56K	Front Cockpit (CLP)	2 liters oxygen remaining (F) 4 liters oxygen remaining (TF)
Spare	--	--	--	--	--	--	
Spare	--	--	--	--	--	--	
GRU/MRU Discrete	Off On	Open Gnd	NA	TBD	TBD	--	Sets CSFDR in mode for data retrieval/readout and system tests.
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	

TABLE 20. F15 DIGITAL SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	MESSAGE NO/WORD	TRANSMISSION RATE	REMARKS
True Airspeed	60 to 1710 Knots	14 Bits	Bit(14)=+0.125Kt Bit(1) = 1,024 Kts	1/1	20/Sec	Source is ADC
Barometric Corrected Pressure Altitude	-1570 Ft to 39,390 Feet	16 Bits	Bit(15)=+1.25 Ft Bit(1) =+20,480 Ft Bit(0) = 40,960 Ft	1/10	20/Sec	Source is ADC
Pitch Attitude	$\pm 180^{\circ}$	14 Bits	Bit(13)=+0.022° Bit(1) = +90° Bit(0) = -180°	1/7	20/Sec	Source is INU
Bank Angle (Roll Attitude)	$\pm 180^{\circ}$	14 Bits	Bit(13)=+0.022° Bit(1) =+90° Bit(0) =-180°	1/8	20/Sec	Source is INU
Normal Acceleration	-4G's to +12G's	16 Bits	Bit(15)=+0.00049G Bit(1)=+8G's Bit(0)=-16G's	30/4	20/Sec	Source is PSDP
True Heading	$\pm 180^{\circ}$	14 Bits	Bit(13)=+0.022° Bit(1) =+90° Bit(0) =-180°	1/9	20/Sec	Source is INU
True Angle of Attack (AOA)	-10.1° to +35.1°	15 Bits	Bit(14) = +0.0027° Bit(1) = +22.5° Bit(0) = -45°	1/2	20/Sec	Source is ADC
Total Fuel Weight	0-23,530 (A/B) 0-35,100 (C/D)	16 Bits	Bit(15) = +2 Lbs Bit(1) = +32,768 Lbs	30/5	20/Sec	Source is PSDP
Mach Number	0.0985 to 3.0195 Mach	15 Bits	Bit(14)=0.0002 Mach Bit(1) = 2 Mach	1/6	20/Sec	Source is ADC

TABLE 21. F15 DIGITAL SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	MESSAGE NO/WORD	TRANSMISSION RATE	REMARKS
Lateral Stick Force	0 to 17.5 Lbs	16 Bits	Bit(15)=+0.001 Lbs Bit (1)=16 Lbs	30/6	20/Sec	Source is PSDP

TABLE 22. F16 ANALOG SIGNALS

TABLE 22 F16 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Rudder Position (δ R)	$\pm 30^{0}$	0 to 6.25 VRMS, 400 Hz	See Note 2	TBD	NA	≤ 400	$\geq$50K	LVDT
Left Horizontal Tail Position (δ HL)	$\pm 25.15^{0}$	0 to 5.6 VRMS, 400 Hz	See Note 3	TBD	NA	≤ 400	$\geq$50K	LVDT
Right Horizontal Tail Position (δ HR)	$\pm 25.15^{0}$	0 to 5.6 VRMS, 400 Hz	See Note 3	TBD	NA	≤ 400	$\geq$50K	LVDT
Left Flaperon (δ FL)	-20^{0} + $+23^{0}$	0 to 5.6 VRMS, 400 Hz	See Note 1	TBD	NA	≤ 400	$\geq$50K	LVDT
Right Flaperon (δ FR)	-20^{0} to $+23^{0}$	0 to 5.6 VRMS, 400 Hz	See Note 1	TBD	NA	≤ 400	$\geq$50K	LVDT
Engine RPM (N1)	8,000-15,000 RPM	1,900-9,500 Hz	0.633 Hz/RPM	TBD	NA	≤ 200	$\geq$50K	
Engine RPM (N2)	1,320-15,100 RPM	198-2,265 Hz	0.15 Hz/RPM	TBD	NA	≤ 200	$\geq$50K	
Fuel Flow (ωf)	0 to 80 KPPH	26 VRMS, 400 Hz	TBD	TBD	NA	$\leq$ 20K	$\geq$500K	Synchro
Fuel Quantity (FQ)	0 to 20,000 Lbs	0 to 5 VDC	See Note 4	TBD	NA	≤ 400	$\geq$50K	DC ratiometric
Fan Turbine Inlet Temperature (FTIT)	0^{0} to 1200^{0}C	0 to 5VDC	4.166MV/^{0}C	TBD	TBD	$\leq$ 5K	$\geq$100K	Approval expected by GD

TABLE 23. F16 ANALOG SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	SOURCE ACCURACY	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIN. LOAD (IN OHMS)	REMARKS
Power Lever Angle (PLA)	7.75° to 57°	0 to -10 VDC	-0.1875 x (PLA-5.0825)	TBD	TBD	$\leq$2K	$\geq$500K	DC Differential Block 10 and up
Stick Force Elevator (FE)	$\pm$32 Lbs	0 to 0.64 VRMS, 800 Hz	19 MV/Lb	TBD	NA	$\leq$20K	$\geq$500K	LVDT - Signal scaling is non-linear.
Stick Force Aileron (FA)	+17 lbs	0 to 0.646 VRMS, 800 Hz	38 MV/Lb	TBD	NA	$\leq$20K	$\geq$500K	LVDT Signal scaling is non-linear.
Rudder Pedal Force (δ RF)	+110 Lbs	0 to 6.82 VRMS, 800 Hz	62 MV/Lb	TBD	NA	$\leq$20K	$\geq$500K	LVDT - Signal scaling is non-linear
Leading Edge Flap Position Feedback (δ LE)	-2° to $+25^{\circ}$	+0.75 to +14.25 VDC	.5(δ LE + 1.75)	TBD	NA	$\leq$2K	$\geq$500K	
A.B. Nozzle Position (A/B NC)	0° to 240°	26 VRMS 400 Hz	TBD	TBD	NA	$\leq$20K	$\geq$500K	Synchro

NOTES:

1. $VR = \frac{Eo}{Ex} = 0.1 \left[\sqrt{\left[12.605 + 5.8 \text{ SIN } (\delta_{FL} - 1.5)\right]^2 + 1} - 12.645 \right]$
2. $VP = \frac{Eo}{Ex} = 0.477 \text{ SIN } \quad R$
3. $VP = \frac{Eo}{E_x} = 0.1 \left[\sqrt{(12.605 + 5 \text{ SIN } \delta_{HL})^2 + 1} - 12.645 \right]$
4. $VP = \frac{Eo}{Ex} = \frac{5}{120,000} \quad F()$

TABLE 24. F16 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MIMIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Fuel Hot	Normal Overheat	0 VDC 28 VDC	NA	< 2K	100K	P260-12	
Engine Electronic Control (EEC)	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P260-24	
Backup Fuel Control (BUC)	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P260-17	Engine operating off this BUC
Power Lever Angle (PLA)	Not 4^o 4^o	0 VDC 28 VDC	NA	< 2K	100K	Engine Interface	
	Not 14.5^o 14.5^o	0 VDC 28 VDC	NA	< 2K	100K		
	Not 18^o 18^o	0 VDC 28 VDC	NA	< 2K	100K		
	Not 39.5^o 39.5^o	0 VDC 28 VDC	NA	< 2K	100K		
Power Lever Angle (PLA)	Not 54^o 54^o	0 VDC 28 VDC	NA	< 2K	100K	Engine Interface	

TABLE 25. F16 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Oil Pressure (OP)	Normal Low	0 VDC 28 VDC	NA	< 2K	100K	TBD	
Main Generator Fail	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P245-1	
Emergency Generator Fail	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P245-2	
Flight Control Battery Discharge	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P245-3	
Aircraft Battery Fail	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P245-4	
Second DC Converter Fail	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	TBD	
Hydraulic Pressure A (HA)	Normal Low	0 VDC 28 VDC	NA	< 2K	100K	TBD	Primary system pressure Fail < 1000 psi
Hydraulic Pressure B (HB)	Normal Low	0 VDC 28 VDC	NA	< 2K	100K	TBD	Utility system pressure Fault < 1000 psi

TABLE 26. F16 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Takeoff/Landing Configuration (To/Ldg)	Takeoff Landing	0 VDC 28 VDC	NA	$< 2K$	100K	P2-B	Landing gear not down and locked or trailing edge flap not positioned properly.
Speed Brake (SB)	0^{o} 60^{o}	0 VDC 28 VDC	NA	$< 2K$	100K	TBD	
Speed Brake (SB)	$< 43^{o}$ $> 43^{o}$	0 VDC 28 VDC	NA	$< 2K$	100K	TBD	
Engine Fire (EF) Master Warning	No Fire Fire	0 VDC 28 VDC	NA	$< 2K$	100K	P2-A	Engine compartment fire.
Overheat	Normal Overheat	0 VDC 28 VDC	NA	$< 2K$	100K	P260-19	Fire in nacelle, emergency power unit locale and in ECS Turbine Bay
Equipment Hot	Normal Overtemp	0 VDC 28 VDC	NA	$< 2K$	100K	P260-8	Avionics cooling air
Forward Fuel Low	Normal Low	0 VDC 28 VDC	NA	$< 2K$	100K	P260-18	Tank contains $<$ 400 pounds of fuel (F16A); $<$ 250 pounds for F16B.
Aft Fuel Low	Normal Low	0 VDC 28 VDC	NA	$< 2K$	100K	P260-11	Tank contains $<$ 250 pounds of fuel (F16A); $<$ 400 pounds for F16B.

TABLE 27. F16 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Canopy Closed (CC)	Open Closed	0 VDC 28 VDC	NA	< 2K	100K	P3-D	
Hook	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P260-29	Caution if tail hook is not locked up.
Anti-Skid	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P260-6	
Oxygen Low	Normal Low	0 VDC 28 VDC	NA	< 2K	100K	P260-4	Oxygen pressure below 4.2 psi or quantity below 0.5 liter.
Nose-Wheel (NW) Steering Failure	Normal Fault	0 VDC 28 VDC	NA	< 2K	100K	P260-27	Applies only to electrical system failure
Cabin Pressure	Normal Low	0 VDC 28 VDC	NA	< 2K	100K	P260-13	Fault if cabin pressure is above 27,000 feet (5 psi).
Seat Not Armed	Armed Not Armed	0 VDC 28 VDC	NA	< 2K	100K	P260-16	
(11) Spares	--	--	--	--	--	--	
GRU/PGU Discrete	Off On	Open Gnd	NA	TBD	TBD	--	Sets CSFDR in mode for data retrieval/readout and system test.
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	

TABLE 28. F16 DISCRETE SIGNALS

PARAMETER	SIGNAL RANGE	SIGNAL SCALING	RESPONSE TIME	SOURCE IMPEDANCE (IN OHMS)	SUGGESTED MINIMUM LOAD (IN OHMS)	AIRCRAFT INTERFACE	REMARKS
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	
Aircraft Identification	Off On	Open Gnd	NA	TBD	TBD	--	

TABLE 29. F16 DIGITAL SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	BLOCK/ WORD	TRANSMISSION RATE	REMARKS
True Airspeed (A/S)	70 to 1760 knots	14 Bits + Sign	Bit(15)=0.125 Kt Bit(2)=1,024 Kts Bit(1)=Sign	C01/04	25/Sec	Source is CADC
Barometric Altitude (HB)	-1500 to +80,000 Ft	15 Bits + Sign	Bit(16)=2.5 Ft MSB(2)=40,980 Ft Bit(1)=Sign	C01/03	25/Sec	Source is CADC
Pitch Attitude (θ)	$\pm 110^0$	13 Bits + Sign	Bit(14)=0.022^0 Bit(2)=90^0 Bit(1)=Sign	I01/11	50/Sec	Source is INU
Roll Attitude (ϕ)	$\pm 180^0$	13 Bits + Sign	Bit(14)=0.022^0 Bit(2)=90^0 Bit(1)=Sign	I01/10	50/Sec	Source is INU
Normal Acceleration (G)	$\pm$10 G's	11 Bits + Sign	Bit(12)=0.0078G Bit(2)=8G's Bit(1)=Sign	H01/06	50/Sec	Source is INU
True Heading (ψ)	$\pm 180^0$	13 Bits + Sign	Bit(14)=0.022^0 Bit(2)=90^0 Bit(1)=Sign	I01/12	50/Sec	Source is INU
True Angle of Attack (α)	-5^0 to 40^0	14 Bits + Sign	Bit(15)=0.011^0 Bit(2)=90^0 Bit(1)=Sign	C01/07	25/Sec	Source is CADC
Mach Number (M)	0.1 to 3.0 Mach	14 Bits + Sign	Bit(15)=0.00085M Bit(2)=2 Mach Bit(1)=Sign	C01/05	25/Sec	Source is CADC

TABLE 30. F16 DIGITAL SIGNALS

PARAMETER	DATA RANGE	SIGNAL RANGE	SIGNAL SCALING	BLOCK/ WORD	TRANSMISSION RATE	REMARKS
Sideslip Angle (β)	$\pm 20^0$	15 Bits + Sign	Bit(16)=0.0055^0 Bit(2)=90^0 Bit(1)=Sign	F10/17	50/Sec	Source is Flight Control Computer
Central Air Data Computer Status	Go No Go	8 Bits	--	C01/01	25/Sec	Source is CADC
Fire Control Computer Status	Go No Go	16 Bits	--	F10/01	50/Sec	Source is FCC
Manchester Data Word	Fault Status Info	66 Bits (See Tables 31, 32, 33)	--	--	40.96 KHZ	Source is Flight Control Computer

TABLE 31. MANCHESTER DATA WORD

BIT NO.	FUNCTION	LOGIC LEVEL ASSIGNMENT
1	Fixed Leading Logic 1	1
2	Rudder Servo Disengagement	0
3	Right Pitch Servo Fail Indication	0
4	Left Pitch Servo Fail Indication	0
5	Right Flaperon Servo Fail Indication	0
6	Left Flaperon Servo Fail Indication	0
7	Rudder Servo Fail Indication	0
8	Right Pitch Servo Disengagement	0
9	Left Pitch Servo Disengagement	0
10	Right Flaperon Disengagement	0
11	Left Flaperon Disengagement	0
12	Yaw Branch Fail A	0
13	Yaw Branch Fail B	0
14	Yaw Branch Fail C	0
15	Yaw Branch Fail D	0
16	Left Flaperon Branch Fail A	0
17	Right Flaperon Branch Fail B	0
18	Spare Bit	1
19	Left Flaperon Branch Fail B	0
20	Right Flaperon Branch Fail B	0
21	Spare Bit	1
22	Left Flaperon Branch Fail C	0
23	Right Flaperon Branch Fail C	0
24	Manual Pitch Override	1
25	Left Flaperon Branch Fail D	0
26	Right Flaperon Branch Fail D	0
27	Branch C Stores • $\overline{\text{SLO Flight}}$	1
28	Right Horizontal Branch Fail A	0
29	Left Horizontal Branch Fail A	0
30	Pitch Integrator Fail A	0
31	Right Horizontal Branch Fail B	0

TABLE 32. MANCHESTER DATA WORD

BIT NO.	FUNCTION	LOGIC LEVEL ASSIGNMENT
32	Left Horizontal Branch Fail B	0
33	Pitch Integrator Fail B	0
34	Right Horizontal Branch Fail C	0
35	Left Horizontal Branch Fail C	0
36	Pitch Integrator Fail C	0
37	Right Horizontal Branch Fail D	0
38	Left Horizontal Branch Fail D	0
39	Pitch Integrator Fail D	0
40	Second Fail Light On	0
41	First Fail Light On	0
42	Yaw Light On	0
43	Roll Light On	0
44	L/H Horiz. Tail S.A. fail	0
45	R/H Horiz. Tail S.A. fail	0
46	L/H Flaperon S.A. fail	0
47	R/H Flaperon S.A. fail	0
48	Pitch Light On	0
49	Rudder S.A. fail	0
50	Right Horiz. Servo Position $>5^{\circ}$ TED	0
51	Left Horiz. Servo Position $>5^{\circ}$ TED	0
52	Right Flaperon Servo Position $>$ 1.65 TED	0
53	Left Flaperon Servo Position $>$ 1.65 TED	0
54	Rudder Servo Position $> 6^{\circ}$ Left	0
55	STBY Gain Lamp ON	0
56	RHT Command $> 5^{\circ}$ TED	0
57	LHT Command $> 5^{\circ}$ TED	0
58	RF Command $>$1.65 TED	0
59	LF Command $>$ 1.65 TED	0
60	Rudder Command $> 6^{\circ}$ Left	0

TABLE 33. MANCHESTER DATA WORD

BIT NO.	FUNCTION	LOGIC LEVEL ASSIGNMENT
61	Triplex AOA > 29°	1
62	Caution Reset	1
63	Electrical Reset	1
64	Branch D WOW	1
65	Spare bit	1
66	Parity bit	Forces odd number of logic 1's

TABLE 34. BASELINE PARAMETER LIST APPLIED TO AIRFRAMES

PARAMETERS	AIRFRAME RELATED PARAMETERS		
	A10	F15	F16
AIRFRAME			
AIRSPEED (TRUE)	DIGITAL (CALIBRATED)	DIGITAL (TRUE)	DIGITAL (TRUE)
ALTITUDE (BAROMETRIC)	DIGITAL	DIGITAL	DIGITAL
PITCH ATTITUDE	DIGITAL	DIGITAL	DIGITAL
BANK ANGLE (ROLL ATTITUDE)	DIGITAL	DIGITAL	DIGITAL
NORMAL LOAD FACTOR (VERTICAL G'S)	DC ANALOG (6)	DIGITAL	DIGITAL
HEADING	DIGITAL	DIGITAL	DIGITAL
ANGLE OF ATTACK (TRUE)		DIGITAL	DIGITAL

E-8433

TABLE 35. BASELINE PARAMETER LIST APPLIED TO AIRFRAMES (CONTINUED)

	AIRFRAME RELATED PARAMETERS		
PARAMETERS	A10	F15	F16
PRIMARY FLIGHT CONTROLS			
RUDDER POSITION	DC ANALOG (LEFT) DISCRETE (1–RUDDER LIMITING)	SYNCHRO (2–L&R) DISCRETE (1–RUDDER LIMITING)	LVDT
ELEVATOR POSITION	DC ANALOG DISCRETE (DISENGAGE) DISCRETE (2–JAM LIGHTS)	DC ANALOG (2–L&R STABILATOR)	LVDT (2–L&R HORIZONTAL TAIL)
AILERON POSITION	DC ANALOG DISCRETE (DISENGAGED) DISCRETE (2–L&R TAB WARNING LIGHT) DISCRETE (2–L&R TAB SHIFTER SWITCH) DISCRETE (2–L&R JAM LIGHT)	SYNCHRO (2–L&R)	LVDT (2–L&R FLAPERON)
ELEVATOR LINKAGE RATIO		LVDT	

E–8427

TABLE 36. BASELINE PARAMETER LIST APPLIED TO AIRFRAMES (CONTINUED)

PARAMETERS	AIRFRAME RELATED PARAMETERS		
	A10	F15	F16
ENGINE RELATED			
ENGINE RPM			
FAN (N1 OR NF)	FREQUENCY (2–L&R)	FREQUENCY (2–L&R)	FREQUENCY
CORE (N2 OR NG)	FREQUENCY (2–L&R)	FREQUENCY (2–L&R)	FREQUENCY
ENGINE FUEL			
FLOW			SYNCHRO
QUANTITY (TOTAL)	DC ANALOG	DIGITAL	DC ANALOG
PRESSURE	DISCRETES (2–L&R)	DISCRETES (2–L&R PUMP)	
TEMPERATURE (FUEL HOT)		DISCRETE	DISCRETE
ELECTRONIC CONTROL		DISCRETE (2–L&R)	DISCRETE (2–EEC&BUC)
ENGINE EGT		DISCRETE (2–L&R FTIT OVERTEMP)	DC ANALOG (FTIT)
	DISCRETE (2–L&R ENGINE HOT)	DISCRETE (2–L&R BLEED AIR LEAK TEMP)	
		DISCRETE (INLET ICE)	
THROTTLE POSITION	DC ANALOG (2–L&R PLA)	SYNCHRO (2–L&R PLA)	DC ANALOG (PLA) DISCRETE (5–PLA)
OIL PRESSURE	DISCRETE (2–L&R)	DISCRETE (2–L&R)	DISCRETE

E–8431

TABLE 37. BASELINE PARAMETER LIST APPLIED TO AIRFRAMES

	AIRFRAME RELATED PARAMETERS		
PARAMETERS	A10	F15	F16
ELECTRICAL SYSTEMS			
GENERATOR OUTPUT	DISCRETE (2–L&R)	DISCRETE (2–L&R)	DISCRETE (MAIN) DISCRETE (EMER.)
INVERTER OUTPUT	DISCRETE (2–L&R DC CONVERTER) DISCRETE (INSTRUMENT INVERTER)	DISCRETE (2–L&R DC GENERATOR) DISCRETE (EMER. DC BUS)	DISCRETE (FC BATTERY) DISCRETE (A/C BATTERY) DISCRETE (2ND DC CONVERTER)
HYDRAULIC SYSTEMS			
HYDRAULIC PRESSURE	DISCRETE (2–L&R) DISCRETE (2–L&R SHUTOFF VALVE)	DISCRETE (4–L&R) DISCRETE (2–L&R PUMP)	DISCRETE
UTILITY HYDRAULIC PRESSURE		DISCRETE (2–L&R)	DISCRETE
OTHER			
MASTER CAUTION	THE MASTER CAUTION DISCRETE OR'S IN A LARGE NUMBER OF FAULT CONDITIONS. THE PRIMARY FAULTS ASSOCIATED WITH THE MASTER CAUTION DISCRETE HAVE BEEN INDIVIDUALLY ADDED TO THE PARAMETER LIST WITH THE ASSOCIATED PARAMETRIC DATA.		

E–8430

TABLE 38. SECONDARY PARAMETER LIST APPLIED TO AIRFRAMES

PARAMETER	AIRFRAME RELATED PARAMETER		
	A10	F15	F16
AIRFRAME			
MACH NUMBER	DIGITAL	DIGITAL	DIGITAL
SIDESLIP ANGLE	N/A	N/A	DIGITAL
LANDING GEAR POSITION	DISCRETE	DISCRETE (WOW)	DISCRETE (TO/LDG)
FLIGHT CONTROLS			
STICK POSITION OR FORCE	N/A	N/A (MUST ADD SENSORS)	LVDT (2-LONGITUDINAL & LATERAL STICK FORCES)
CAS ROLL		DISCRETE	
SLAT POSITION	DISCRETE		
CAS PITCH		DISCRETE	
RUDDER PEDAL POSITION OR FORCE			LVDT (FORCE)
TRIM (ALL AXES)			
CAS YAW		DISCRETE	
SPEED BRAKE POSITION	LVDT	DISCRETE	DISCRETE (2)
FLAP POSITION	DISCRETE (2)	DISCRETE	DC ANALOG
STABILITY AUGMENTATION SYSTEM (SAS)	DISCRETE (PITCH/YAW)		

E-8429

TABLE 39. SECONDARY PARAMETER LIST APPLIED TO AIRFRAMES

PARAMETER	AIRFRAME RELATED PARAMETER		
	A10	F15	F16
AVIONICS			
AIR DATA COMPUTER (ADC) STATUS	DISCRETE (4-HARS, INS, CADC, ALPHA MACH)	DISCRETE (2-ADC, CC)	DIGITAL
FIRE CONTROL SYSTEM (FCS)STATUS	DISCRETE		DIGITAL DISCRETE (EQUIPMENT HOT)
ENGINE RELATED			
FIRE WARNING	DISCRETE (2-L&R ENGINE)	DISCRETE (2-L&R ENGINE)	DISCRETE (2 ENGINE, NACELLE/EPU LOCALE)
FUEL QUANTITY (PER TANK)			DISCRETE (2 FORWARD & AFT)
FAN TURBINE INLET TERMPERATURE (FTIT)	THIS PARAMETER ADDED TO BASELINE LIST IN LIEU OF EGT		
AFTERBURNER (A/B) POSITION		SYNCHRO (L&R)	SYNCHRO
STARTER			
OIL QUANTITY			
OTHER			
EPU/APU	DISCRETE (ARE)		
PADDLE SWITCH			
COMMUNICATION TRANSIT			
OUTSIDE AIR TEMPERATURE (OAT)			

TABLE 40. OTHER PARAMETER CONSIDERATIONS

PARAMETER	AIRFRAME RELATED PARAMETER		
	A10	F15	F16
CANOPY LOCK/UNLOCK	DISCRETE	DISCRETE	DISCRETE
STALL WARNING	DISCRETE	DISCRETE	
HOOK		DISCRETE	DISCRETE
ANTI-SKID		DISCRETE	DISCRETE
OXYGEN LOW		DISCRETE	DISCRETE
NOSE-WHEEL STEERING FAIL	DISCRETE		DISCRETE
CABIN PRESSURE			DISCRETE
SEAT NOT ARMED			DISCRETE

E-8432

because they are already available and provide an equivalent of the desired information. Alternatively, surface position measured at the input to the actuators could also be used and is available from the standby channel of the fly-by-wire flight control system.

Engine Related Parameters

Engine related parameters vary between the airframes. The A10 has two (2) GE-TF34 engines, the F15 has two (2) Pratt & Whitney F100 engines and the F16 has a single Pratt & Whitney F100 engine. The TF34 has no after-burner where the F100 has an after-burner. The engine speeds for both Gas Generator and Fan are available as frequencies on all three (3) aircraft.

Fuel Flow is available only on the F16. Total fuel weight is available on the F15 data bus. Fuel quantity is available on the F16 as a DC ratiometric signal. Fuel quantity sensors are available on all A10 aircraft, however, the structural monitoring system provides excitation only on every tenth aircraft. The CSFDR would have to excite this sensor on the other nine (9). Fuel pressure is available as discretes on the A10 and F15 and is not available on the F16. Fuel Hot discretes and Electronic Engine Control (EEC) status discretes are available on the F15 and F16 but is not applicable to the A10 which has a different engine.

Engine EGT or alternately FTIT is not currently available as high level analog signal on any of the three (3) aircraft; however, FTIT is expected to be added to the F16 in a manner which can provide a suitable high level signal to the CSFDR. On the F15, FTIT over-temperature discretes are available as a substitute. On the A10 engine over-temperature discretes are available as substitute parameters.

Throttle position sensors are not standard on any of the aircraft except Block 10 F16 aircraft and above. The A10 (in every other aircraft for left PLA only) and F15 will require addition of a sensor to each throttle.

Engine oil pressure is available only as a discrete on all engines of each airframe.

Electrical and Hydraulic System

Electrical and hydraulic systems on all three (3) aircraft are monitored via fault discretes on each system.

Other

The master caution discrete is an or of a number of primary faults most of which will be monitored as individual fault discretes in the CSFDR concept.

SUMMARY

The parameter list applicable to all CSFDR configurations is summarized in Table 41. These parameters provide a minimum CSFDR configuration defined by the Air Force as Configuration II; however, the additional cost of adding the secondary

TABLE 41. SUMMARY OF A10, F15, F16 PARAMETER SIGNAL COMMONALITY

BASELINE PARAMETERS

APPLICABLE TO AF CONFIGURATION II

SIGNAL TYPES	AIRFRAME		
	A10	F15	F16
Digital			
1553	5	8	7
(*) Special	---	---	1
DC Analog			
10V Range	6	2	1
5V Range	6	---	2
AC Analog			
Synchro (26V, 400 Hz)	1	6	1
LVDT (26V, 400 Hz)	---	---	5
Frequency	4	4	2
Discretes	26	26	16

GD

(*) Special digital fly-by-wire fault status

list of parmeters is minimal from the CSFDR and airframe effort cost standpoints and is therefore included as integral part of the Configuration II system concept.

SECONDARY PARAMETERS

Airframe Parameters

Mach number is available as a digital signal on all three (3) airframes. Side slip angle is not available on the A10 and F15; it is available on the F16 data bus. Discretes indicative of landing gear position are available on all aircraft.

Flight Control Parameters

On the A10 flight controls, the surface position and the stick are directly connected except for disconnect of a surface due to a jamb. The disconnects are indicated by discrete monitoring of surface positions and the disconnect discretes should be adequate for the A10. Monitoring the F15 stick position requires adding stick sensors. The F16 has LVDT's on the stick which provide stick forces. Rudder position is only available on the F16 which provides an LVDT signal. The A10 has stability augmentation system engage discretes for pitch and yaw. The F15 has Control Augmentation System engage discretes for pitch, roll and yaw. The F16 has a fly-by-wire flight control which does not have equivalent mode selection. The speed brake position is available on the A10 as an LVDT signal. On the F15 and F16 only discrete signals are available.

Avionics

The Air Data Computer Status on the A10 consists of four (4) discretes indicating mode - Heading and Attitude Reference System (HARS), Inertial Navigation System (INS), Control Air Data Computer (CADC) and ALPHA Mach Computer. The F15 has two (2) status discretes - Air Data (ADC) Computer and Control Computer (CC). The F16 has an eight (8) bit status word for the Central Air Data Computer (CADC). The Fire Control System (FCS) status is available on A10 as a discrete and on the F16 as a sixteen (16) bit data word. On the F15, the only fire control status available is the fire control radar status.

Engine Related

Fire warning discretes are available on all three (3) airframes. Fuel low warning is available on the F16. After-burner position is available on the F15 and F16 but is not applicable to the A10 which has no after-burner.

SUMMARY

The secondary parameter signal commonality is summarized in Table 42. This table summarizes signal type requirements for the three (3) aircraft types. This table combined with Table 41 provides an expanded capability CSFDR defined by the Air Force as Configuration I.

TABLE 42. SUMMARY OF A10, F15, F16 PARAMETER COMMONALITY

SECONDARY PARAMETERS

SIGNAL TYPES	AIRFRAME		
	A10	F15	F16
Digital			
1553	1	2	4
DC Analog			
15V Range	---	---	1
AC Analog			
Synchro (26V, 400 Hz)	---	2	1
LVDT (26V, 400 Hz)	1	---	---
LVDT (26V, 800 Hz)	---	---	3
*Magnesyn	2	---	---
Discretes	16	14	15

* Fuel Flow

2.2 INSTALLATION STUDIES

Hamilton Standard has, in conjunction with the airframe manufacturers, selected and evaluated potential locations for the major physical elements of the CSFDR on the A10, F15 and F16 aircraft. Preliminary characteristics of the CSFDR units were established at the task outset by Hamilton Standard based on current knowledge of existing technology such that the associated A10, F15 and F16 airframe manufacturer could evaluate unit locations in support of Hamilton Standard. The Air Force expanded baseline parameter list was utilized at the outset so that installation studies began with sensitivity to location of signal sources.

Two candidate configurations were defined to the airframe manufacturers and are illustrated in Figures 1 and 2 with size defined in Table 43. Candidate System I Configratuion is a two (2) unit system consisting of a signal conditioning unit located in the Avionics bay and remote tail mounted unit containing the crash survivable memory module. Candidate System II Configuration is a single unit system where signal conditioning and crash protected memory are in the same unit. The aircraft manufacturer investigated possible locations for both system configurations on his aircraft considering the following factors:

* Location for greatest inherent survivability of FDR data module.
* Effect on aircraft weight and balance due to total installation.
* Minimization of weight, volume and cost through placement of elements.
* Accessibility for any needed maintenance.

The following general rules were invoked for areas to avoid in the aircraft:

* Avoid wet areas or areas immediately adjacent to fuel tankage or any other potential source that could cause high intensity fires.
* Avoid locations direclty below or in front of areas of mass concentration i.e., engines, ordinance, seat rails, main spars or structural members. (Assumption is that majority of mishaps involve attitudes that are initially straight in or upright.)
* Avoid directly mounting on or immediately adjacent to engines as these are the largest mass concentrations that involve longer cool down times during post crash fires.
* Avoid, if possible, areas of sustained high operational ambient temperatures. Heat generators such as main engines and APU's should be avoided. Avoid placement adjacent to and/or in contact with good thermal conducting paths from areas of aerodynamic heating for supersonic aircraft. (Reduces CSFDR reliability and could degrade the life of the data memory

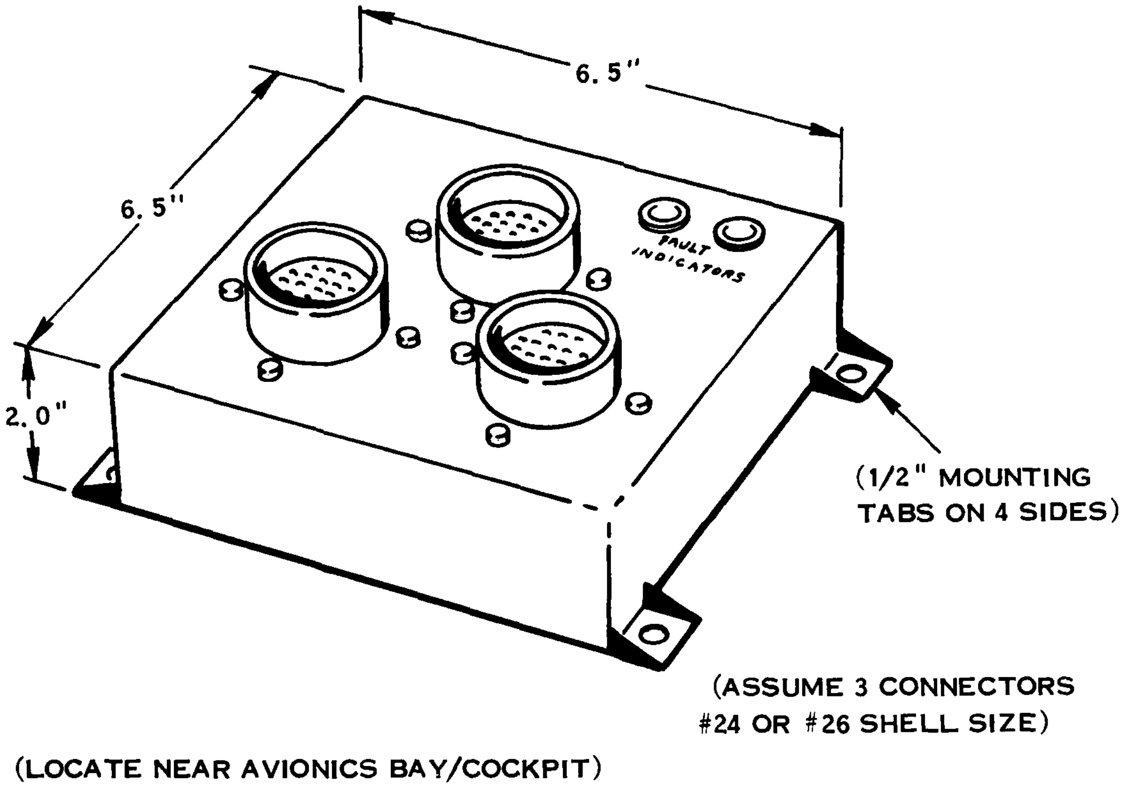
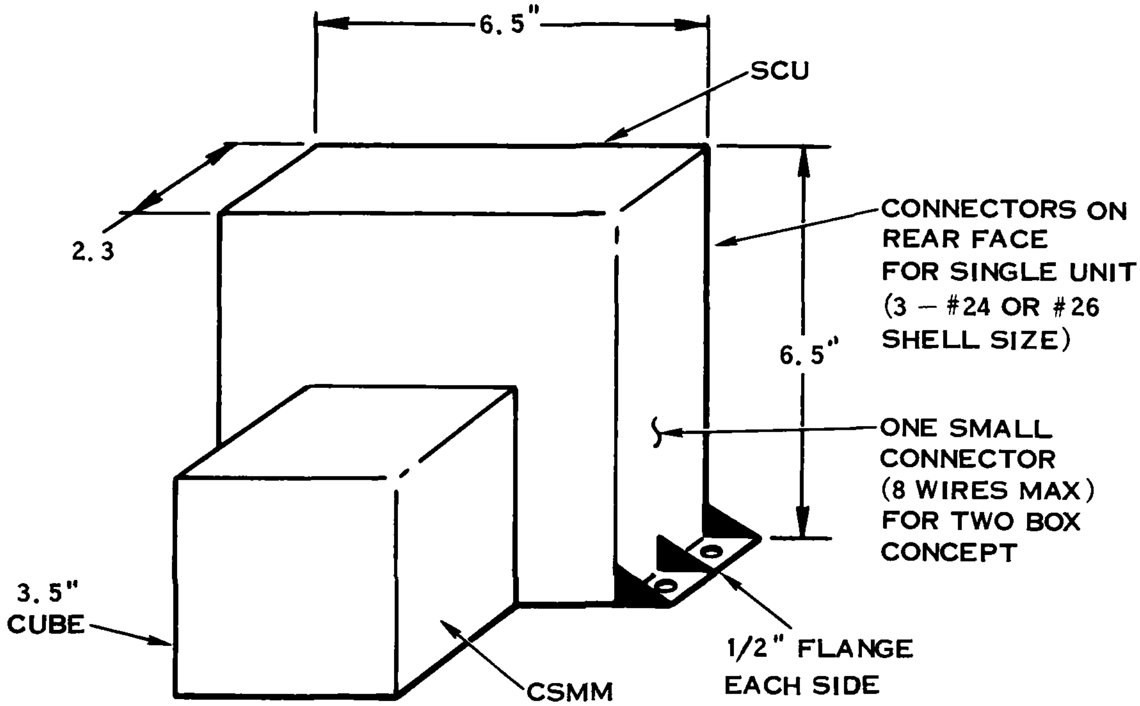


FIGURE 1 SIGNAL CONDITIONER UNIT (SCU) (TWO–BOX UNIT CONCEPT)



(ONE BOX CONCEPT) – (BECOMES REMOTE MEMORY UNIT FOR THE TWO-BOX CONCEPT)

(LOCATE NEAR COCKPIT OR AVIONICS BAY)

NOTE:

FOR TWO-BOX CONCEPT WITH ABOVE CONFIGURATION, DELETE THREE (3) CONNECTORS ON REAR FACE OF SCU AND ADD ONE SMALL CONNECTOR ON RIGHT FACE OF SCU AND REDUCE THICKNESS FROM 2.3" TO 2.0" AND COMBINE WITH FIGURE 1. ALL OTHER DIMENSIONS REMAIN THE SAME. LOCATE IN TAIL AREA FOR REMOTE MEMORY CONCEPT.

FIGURE 2 SIGNAL CONDITIONER UNIT (SCU) & CRASH SURVIVABLE MEMORY UNIT (CSMU) – CONFIG "B"

TABLE 43. PRELIMINARY CSFDR SYSTEM UNIT ATTRIBUTES CONFIGURATION II TECHNOLOGY

Candidate System I:

Signal Conditioning Unit:	5.0 Pounds 6.5" X 6.5" X 2"
Remote Memory Unit: (Electronics)	1.5 Pounds 6.5" X 6.5" X 2"
CSMM:	3.8 Pounds 2.5" X 3.0" X 3.0"

Candidate System II:

Electronics Unit:	5.7 Pounds 6.5" X 6.5" X 2.3"
CSMM:	3.8 Pounds 2.5" X 3.0" X 3.0"

even if the devices can operate in the higher ambients. Also could drive device cost up.)

* Avoid areas of excessively high vibration for the CSFDR units.

The proposed CSFDR continuous operating temperature limits are MIL-E-5400R, -54°C to 71°C, 70,000 feet (Class II). The proposed operational vibration limit is MIL-E-5400 curve IV (10g).

The following priority order of preference for locations of the crash survivable memory module was established.

1. Vertical or angled tail fin.

2. Empennage area or fairing adjacent to tail fin.

3. Canopy area, as high as possible behind aft crew seat.

4. Cockpit area - aft.

5. Trailing edge wing root.

6. Strakes, leading edge wing fairings adjacent to main fuselage structure.

7. Avionics bays - aft and as high as practical.

A10 CSFDR UNIT(S) LOCATION

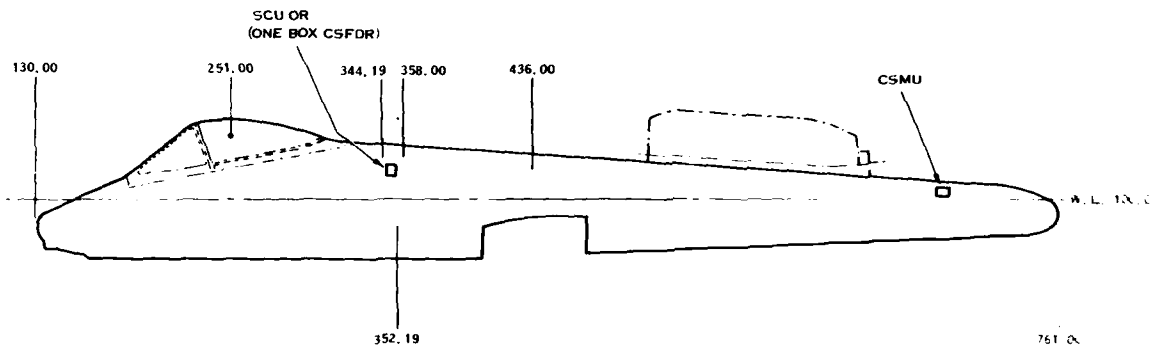
One-Box Concept

The A10 aircraft presented little problem in the location of a CSFDR in either the one-box or two-box concept. The prime location for the one-box concept was identified as being high in the avionics bay aft of the cockpit area between fuselage stations FS 344 and FS 358 and above water line (WL) 105.5 on the right side of the aircraft, see Figure 3. This area is presently occupied by the majority of A10 avionics hardware and is in close proximity to defined CSFDR aircraft interface signals. This area has a benign environment which would be conducive to the reliable operation of an electronics unit meeting the operating requirements of MIL-E-5400R, Class II. This location also involves minimal impact on aircraft wiring.

This location would afford lower survivability compared to a tail mount. External mounting of the engines on the A10 does make a forward mount somewhat more survivable than the F15 and F16 application.

Two-Box Concept

The two-box CSFDR configuration (i.e., Signal Conditioner Unit - SCU and remote Crash Survivable Memory Unit - CSMU) would again be easily accommodated in the A10 aircraft. The SCU would be located at the same location as given for the one-box concept while the remote CSMU would be located in the empennage in the



FUSELAGE – LEFT SIDE

E–8486

FIGURE 3. A10 SELECTED CSFDR UNIT(S) LOCATION

area of the right stabilator at fuselage station FS 688 above WL 100, see Figure 3. Both areas provide a relatively benign environment for the equipment with the additional benefit of providing a relatively survivable location for the remote memory unit. In severe mishaps to date involving the A10 aircraft, the empennage area has survived in relatively large pieces and in the majority of severe mishaps, the stabilators have remained intact and functional following recovery.

The primary drawback is the added cost and weight of the CSFDR in a two-box configuration and the additional wiring to interface the SCU and CSMU.

This configuration would also involve the greatest affect on installed weight and balance since the A10 is tail heavy. The one-box concept involves installation in close proximity to the aircraft center of gravity and would thus add approximately one-third (1/3) as much weight as the two-unit concept.

F15 CSFDR UNIT(S) LOCATION

One-Box Concept

Four (4) candidate locations on the F15 aircraft were evaluated as potential areas in which a one-box CSFDR configuration (including a Signal Conditioner Unit-SCU and a Crash Survivable Memory Unit - CSMU) could be located. These locations included: (Reference Figure 4 and Table 44).

Location 5: Forward of right engine between FS 500 and FS 568 high in the fuselage (above WL 132).

Location 6: In the region of the Gun Bay.

Location 8: Avionics compartment (ECS Bay) below and aft of the cockpit area between FS 380 and FS 415 and between WL 100 and WL 112 on the left side of the aircraft.

Location 9: In the empennage (area of left stabilator).

The Location 5 area was discounted as a possibility due to the extremely high ambient temperatures existing (180°F continuous with up to 418°F transients) in this locale. Present CSFDR technology (i.e., water boiler concept) and state-of-the-art electronics operating temperature limitations render this location unsuitable. The close proximity to fuel tanks and being directly in front of the right engine would reduce somewhat the CSFDR survivability in a severe mishap.

Location 6, in the region of the aircraft armament, not only has the same severe thermal environment as location 5 but in addition would involve exposure of the CSFDR to high vibration levels. This location was also considered unsuitable.

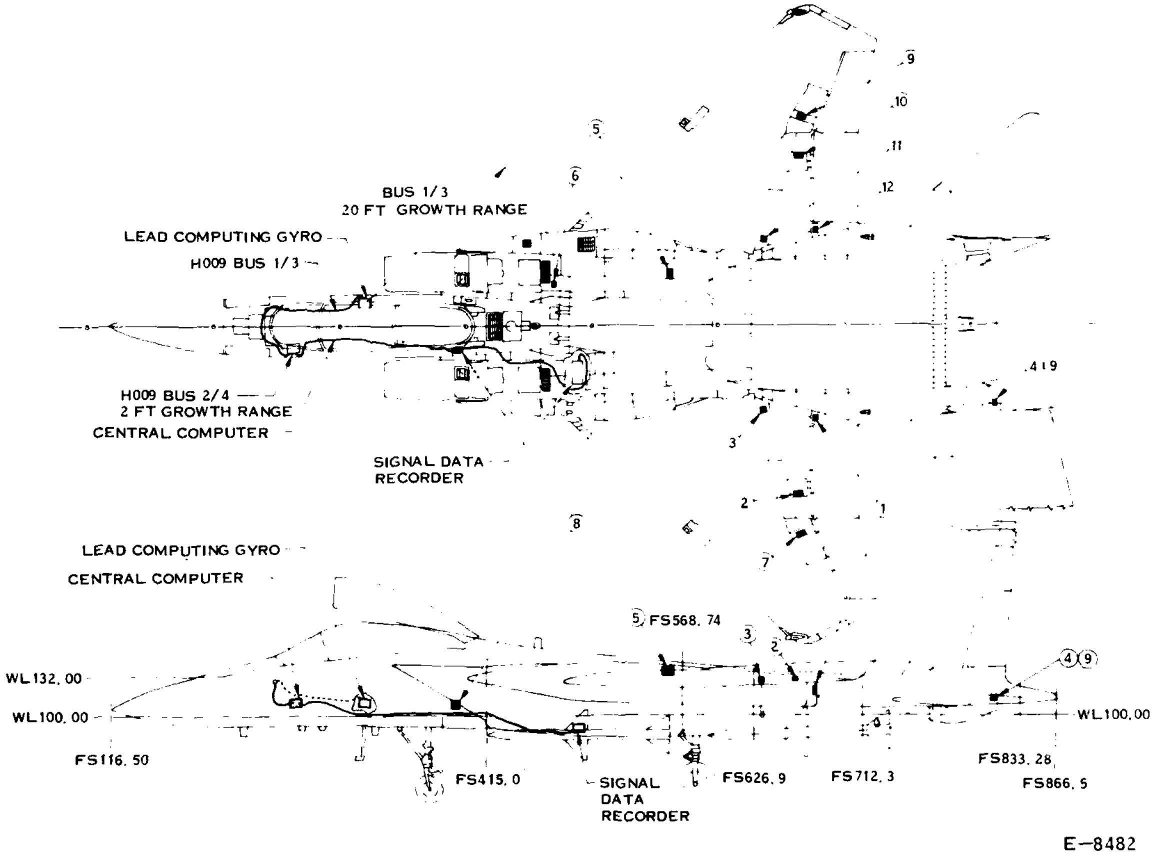


FIGURE 4. F15 CANDIDATE CSFDR LOCATIONS

TABLE 44. F–15 CANDIDATE CSFDR LOCATION SURVEY

LOCATION	CSFDR CONFIGURATION	THERMAL ENVIRONMENT	VIBRATION ENVIRONMENT	COMMENTS
1 OR 12	CSMU	CONTINUOUS 160°F 10 MINUTES 300°F 1 MINUTE 350°F	4	• CLOSE PROXIMITY TO FUEL AND PRIMARY HEAT EXCHANGER MASS • GOOD IMPACT SURVIVABILITY • MAY BECOME INACCESSIBLE AFTER IMPACT
2 OR 10	CSMU	CONTINUOUS 160°F 10 MINUTES 300°F 1 MINUTE 350°F	4	• CLOSE PROXIMITY TO WING FUEL CELL • GOOD IMPACT SURVIVABILITY
3 OR 11	CSMU	CONTINUOUS 160°F 10 MINUTES 300°F 1 MINUTE 350°F	4	• CLOSE PROXIMITY TO FUEL AND PRIMARY HEAT EXCHANGER MASS • GOOD IMPACT SURVIVABILITY • MAY BECOME INACCESSIBLE AFTER IMPACT
4	CSMU	CONTINUOUS 160°F 10 MINUTES 300°F 1 MINUTE 350°F	3	• GOOD IMPACT SURVIVABILITY • SUSCEPTIBLE TO DAMAGE IN EVENT OF ENGINE FIRE OR NOZZLE/TURBINE FAILURES
5	SCU & CSMU OR CSMU	CONTINUOUS 180°F 10 MINUTES 343°F 1 MINUTE 418°F	2	• WOULD REQUIRE H009 MUX BUS REWIRING TO GAIN SUFFICIENT LENGTH • CLOSE PROXIMITY TO FUEL MASS
6	SCU	CONTINUOUS 180°F 10 MINUTES 343°F 1 MINUTE 418°F	9	• REQUIRES SUBSTANTIAL CHANGE • HIGH VIBRATION REGION
7 OR 9	CSMU	CONTINUOUS 160°F 10 MINUTES 300°F	4	• GOOD IMPACT SURVIVABILITY • LOCATION TENDS TO REMAIN ACCESSIBLE AFTER IMPACT
8	SCU	CONTINUOUS 160°F 30 MINUTES 203°F	1	• WET AREA – UNIT MUST BE IMMUNE TO WATER IMPINGEMENT
9	SCU & CSMU SCU & CSMU	CONTINUOUS 160°F 10 MINUTES 300°F 1 MINUTE 350°F	3	• SEE LOCATION 4 ABOVE • OUT OF H009 MUX BUS RANGE • REQUIRES MIL–STD–1553B BUS INTERFACE

E–8472

Location 8 in the ECS Bay provided the best alternative of the locations evaluated even though the thermal environment was beyond MIL-E-5400R, Class II operational conditions (i.e., 160°F continuous, 203°F for 30 minutes). The thirty minute transient at 203°F is not considered to be beyond the capability of state-of-the-art design techniques. A second minor consideration involved water impingement on the CSFDR, however, this condition is not considered beyond resolution either via minor airframe modifications and/or CSFDR protective coating measures. This location is in close proximity to aircraft electrical signal interfaces and would have minimal impact on installation wiring and aircraft weight and balance since it is located forward of the center of gravity in a tail heavy aircraft.

The one major drawback is the location being forward of and below the bulk of the aircraft mass such that the CSFDR could be subjected to high impact and crushing loads in a severe mishap.

Location 9 in the empennage was considered unsuitable because of the high ambient thermal environments and the remoteness from aircraft electrical interfaces which would necessitate excessive wiring runs for analog and digital signals.

Two-Box Concept

For two-box CSFDR configuration (which includes a SCU and a remote CSMU), location 8 was again considered the prime location for the SCU for the reasons defined for the one-box concept.

A variety of locations for the remote CSMU were considered. These included:

Locations 1, 2, 3, 7, 9, 10, 11, 12: All these locations are in the wings (left or right).

Location 4: in empennage (area of left stabilator).

Location 9 in the empennage was considered unsuitable because of the high ambient thermal environments and the remoteness from aircraft electrical interfaces which would necessitate excessive wiring runs for analog and digital signals.

All of the above locations were evaluated from the stand point of impact survivability. In the majority of severe mishaps, the areas shown have remained relatively intact and therefore it may be assumed that the CSMU would provide adequate crash protection for the solid-state storage medium in a severe mishap. However, overriding consideration for all locations defined is the extremely high ambient temperatures involved. In all cases, the thermal environment would make application of state-of-the-art electronics technology highly questionable without major airframe modifications to provide coolant for these areas or providing a higher cost high temperature design. The 300°F and 350°F transient temperatures would cause contemporary electronics performance degradation beyond an acceptable limit and degrade CSFDR reliability well below minimum acceptable standards. In addition, a water boiler concept used for flame protection would be marginal.

Therefore, for the near term CSFDR application on the F15, the one-box concept is recommended. It is felt that the lesser survivability associated with the recommended location (8) is more than offset by the delta penalty in cost and weight of the two-box system.

F16 CSFDR UNIT(S) LOCATION

One-Box Concept

The F16 aircraft presents the most difficult task of CSFDR location owing to the relatively small size of the aircraft and the fact that the engine and fuel storage compartments comprise better than 70% of the total F16 volume.

Considerations for locating the CSFDR included the cockpit area below and aft of the ejection seat. During the course of the study, this area was filled as a result of ECP 350 affecting block III aircraft and up. This leaves this space available on approximately 200 current F16 aircraft. Another location consideration included the aft canopy level area near the lift mechanism. This area was discounted because of interference with the pilot's rear vision and the 40g mount integrity requirement placed on cockpit equipment. Additionally, the F16B would not leave enough space to accommodate present technology CSFDR's in this area.

Installation in areas of the empennage and wing sections were also negated due to the excessive wire run lengths through wet areas to the empennage and severe operational environment in the wing sections. The empennage shelf area just aft of FS 440 in the same general area as the chafe/flare dispenser and tail floodlight is a considered location. It is aft of the plane of rotation of the engine turbine blades and has a thermal environment of -65°F to +165°F with 230°F temperatures (as a result of aerodynamic heating) not to exceed ten (10) minutes in duration over a ten (10) hour period. It is felt the CSFDR technology would function acceptably in this environment provided the transient temperatures were of relatively short duration. The cost and reliability of the CSFDR would both be adversely affected in designing for this environment however.

The most suitable candidate locations were considered to be the aft equipment bay above WL 91 at FS 180 for the F16A and on the left hand lower strake door in the aft equipment bay along WL 91 at FS 158 for the F16B, reference Figure 5. These prime locations defined do offer several distinct advantages.

1. Benign Environment - The operating environment would be conducive to present day CSFDR technology which meets MIL-E-5400R, Class II environmental conditions.

2. Near Aircraft Electrical Interfaces - The location is in close proximitiy to aircraft parametric signal interfaces thus minimizing the length of interconnect wiring and therefore minimizing installation cost and added weight.

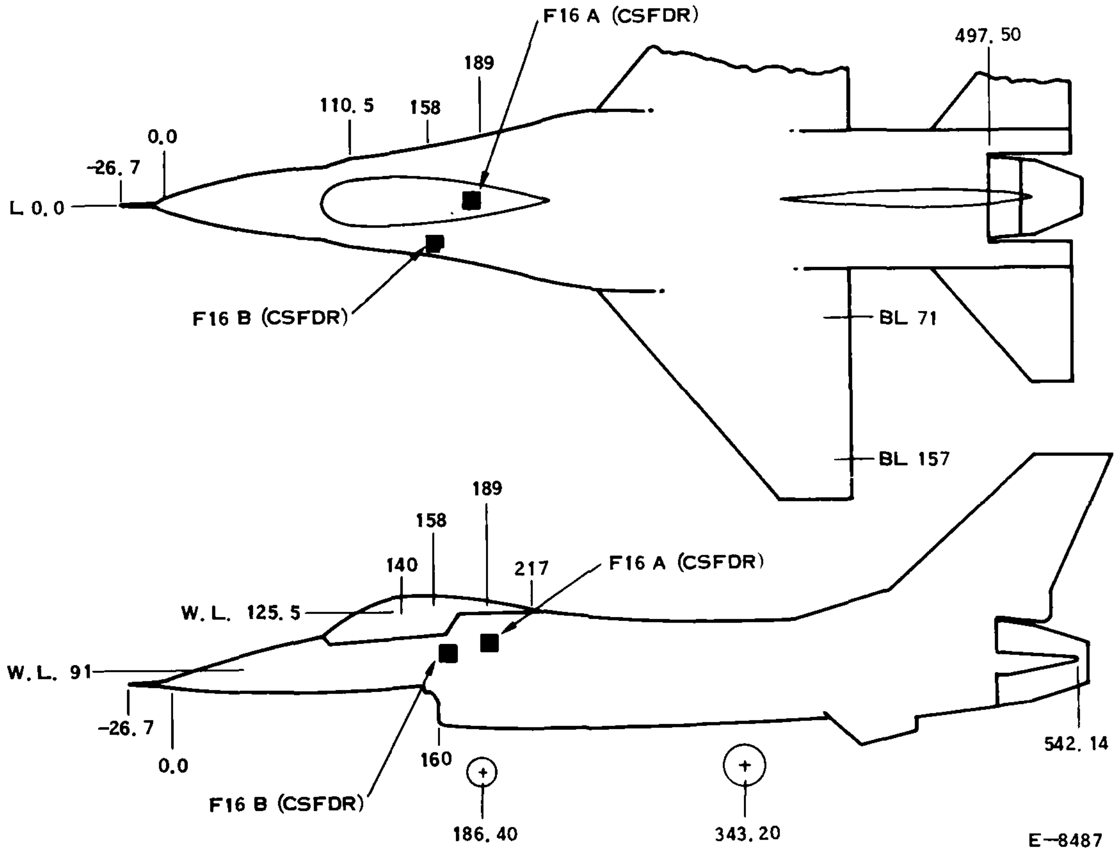


FIGURE 5. F-16 SELECTED CSFDR UNIT LOCATIONS

3. Aircraft Weight & Balance - The location is forward and in close proximity to the aircraft center-of-gravity thus causing minimum impact on aircraft weight and balance.

The one single disadvantage of locating the CSFDR in the avionics bay is the lower survivability characteristics associated with equipment located forward of the greatest aircraft mass. The CSFDR could be subject to high impact and crushing loads; however, a consideration of F16 operational characteristics reduced this risk to some degree. In most F16 mishap scenarios, the fly-by-wire system tends to keep the aircraft in straight and level flight to impact. In 80% of F16 severe mishaps to date,the aircraft has remained in large pieces and the avionics bay equipment has to a great extent remained intact.

Two-Box Concept

The two-box concept for the CSFDR appears to be feasible, in terms of present or available technology, for the F16 aircraft. The major disadvantage is the higher cost associated with this concept. The demonstrated survivable characteristics of the equipment bay appears to offer the most cost effective alternative without compromising retrieval capabilities.

2.3 RECORDER CRASH SURVIVABILITY

The investigation of crash survivability consisted of a review of AFISC mishap data on severe mishaps for fighter, attack and trainer aircraft followed by a study of the recorder module survivability needs using FAR 37.150, TSO-C51a[1] as a base. In addition, the work reported in the Preliminary Design of an Accident Information Retrieval System (AIRS)[2] was also used as a starting point since this report includes an in-depth review of the referenced FAR.

Review of Fighter, Attack and Trainer Mishaps

Mishaps are classified by the Air Force by severity with respect to cost, lost manpower and fatalities as follows:

A. CLASS A MISHAP. A mishap resulting in

(1) Total cost of $200,000 or more for injury, occupational illness, and property damage, or
(2) A fatality, or
(3) Destruction of, or damage beyond economical repair to, an Air Force aircraft.

B. CLASS B MISHAP. A mishap resulting in total cost of $50,000 or more, but less than $200,000, for (1) above factors

(1) U.S. Federal Aviation Regulation Part 37.150 Aircraft Flight Recorder TSO-C51a

(2) H. Ask et al. Preliminary Design of an Accident Information Retrieval System (AIRS) USARTL-TR-77-51, April 1978

C. CLASS C MISHAP. A mishap resulting in

(1) Total damage which costs $300 or more, but less than $50,000, or
(2) An injury or occupational illness which reuslts in a lost workday.
(3) Miscellaneous criteria.

D. CLASS D MISHAP. An injury or occupational illness resulting in

(1) A lost workdav case involving days or restricted work activity, or
(2) A nonfatal case without lost workdays.

While a flight data recorder has utility implications for all mishaps, from a recorder survivability point of view, only severe Class A accidents are of interest in this study segment.

A computer runoff consisting of 368 Class A and B mishaps was received from AFISC. A study of these data indicated that 33.5% of Class A and B mishaps resulted in destruction of the aircraft. From Air Force statistics for calendar years 1979 and 1980, there were 132 Class A accidents out of 225 Class A and B accidents or 59% were Class A.

The above statistical results indicate that 57% of Class A accidents result in destruction of the aircraft. In review meetings with AFISC and through statistical review of data, the following additional facts were highlighted:

(a) 95% of all ground impacts in severe accidents exhibited significant crash fires.

(b) 95% of the above fires resulted in the avionics/cockpit areas being largely consumed.

(c) 30% of the crash sites were "smoking holes" with a few recognizable pieces of wreckage scattered about.

(Factors a, b and c above were developed by AFISC through a review of photographs taken from the mishap files on 88 severe accidents).

(d) 10% of Air Force aircrft go down in water.

(e) 25% of Class A mishaps involve engine problems as a major factor. 25% of Class A involve other mechanical problems.

(f) Looking at 39 severe accidents involving F15, F16 and A10s, in 34% of the cases there was no ejection.

(g) External jettisonable fuel tankage contributes to crash fires only in approximately 10% of crash fires. (This is due to external tankage being consumed in the first part of the flight, and usually jettisoned in an emergency or, during most severe impacts, being separated from the main wreckage.)

(h) The percentage contribution of live ordinance to explosion and crash fire is negligible particularly in peace-time operations.

(i) In 10% or less of severe mishaps, a protracted time scenario is involved. (For purposes of this study, a protacted scenario is one in which the trouble began 15 minutes or more prior to the aircraft being on the ground).

(j) A 400 knot vertical dive to earth is taken as a realistic worst case condition for acceleration impact estimating purposes.

(Factors g through j were arrived at through consensus at meetings with AFISC personnel.)

Figure 6 pictorially summarizes some of the above statistics. The following are conclusions derived from the above factors a through j as they relate to recorder survivability:

(1) A significant portion of Class A accidents have post crash fire; therefore, some degree of fire protection should be provided to the crash survivable memory unit (CSMU) portion of the FDR.

(2) If the economics strongly favor a single box design, location in or around the avionics bay would dictate substantial fire protection for the CSMU.

(3) A signficant portion of Class A accidents are smoking holes resulting from high velocity impact. Signficant impact survivability should be designed into the CSMU.

(4) In a signficant portion of severe accidents there is no ejection; hence, placing the CSMU on the ejection seat has little advantage. Attaching the CSMU to the canopy would have some additional advantage since, in the event of non ejection crashes, the canopy tends to separate on impact. However, restriction of the rearward field of view and mounting for 40g integrity does not make this alternate practical.

(5) Since 10% of aircraft went down in water, the FAA TSO requirement for water submergence of the memory module appears useful. There is no significant cost weight penalty in meeting this requirement. Very few are "lost in the water" of the types considered here. Hence, an activated sonar pinger for locating aircraft under water is not considered necessary.

(6) The probability of jettisonable fuel tankage and live ordinance contributing to crash fire and explosion is low for peace-time operations. Hence these factors can be neglected in the CSMU survivability design.

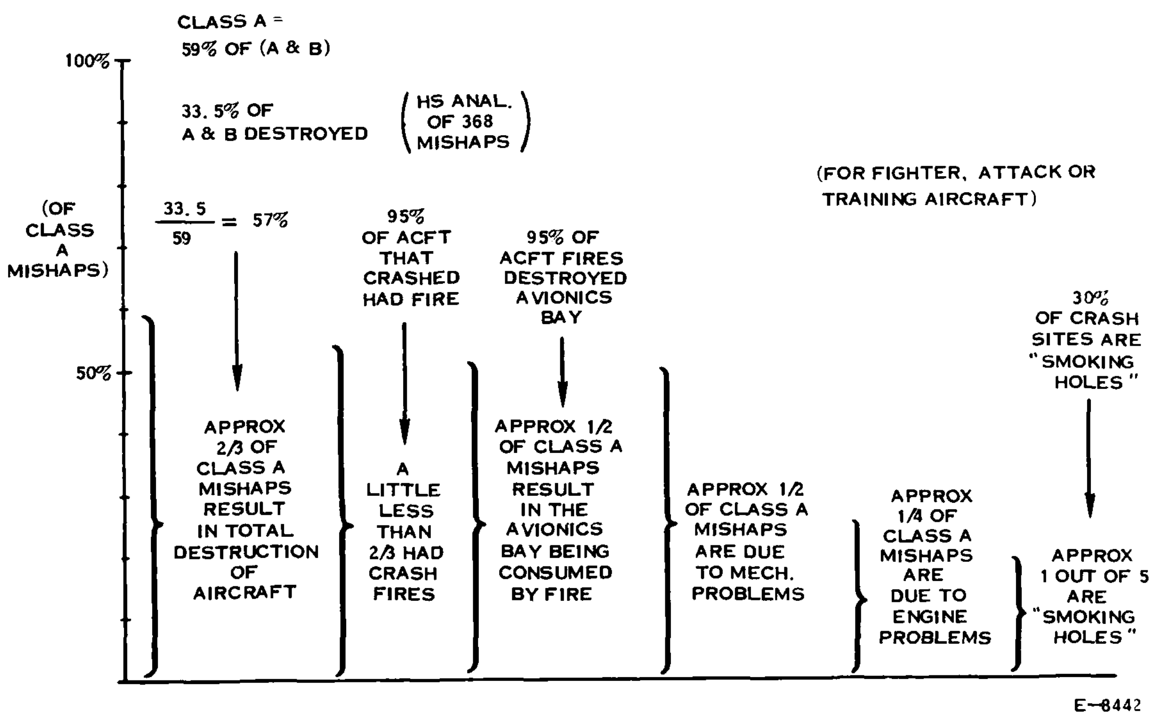


FIGURE 6. PICTORIAL SUMMARY OF AFISC MISHAP DATA

(7) Long duration mishap scenarios (greater than 15 minutes) are uncommon in fighter and attack aircraft. Hence data storage capability representing significantly more than 15 minutes of prior history is not warranted.

General Review of FAA TSO-C51a Requirements in The Light of Fighter/Attack Aircraft Application

Table 45 summarizes the TSO requirements that have been evoked on transport category aircraft for the past twenty years. Since history shows that FDR's are at least 95% survivable designed to these requirements, it can be concluded that the requirements are sufficient for the intended use. (95% survivable in terms of a significant amount of recorded data being recovered.) Detail review of these requirements per reference (2) for rotary wing aircraft concluded that the requirements were also sufficient for helicopter application with the exception of the flame test.

The requirements for rotary wing aircraft could have been relaxed in all areas except fire protection. In fact, per reference (1), it was recommended that the test requirements for fire protection be increased for helicopter application. The Army however, decided to maintain the TSO fire protection requirement as stated in the TSO document.

Concerning the balance of the TSO requirements, for uniformity and the possibility of civil versions of the aircraft and with little cost penalty, it was decided to let the remaining tests and levels stand. For a fighter attack application, there are specification areas where, due to higher aircraft velocities and potential differences in fuel gross vehicle weights, requirements for impact, penetration and fire resistance are in need of review.

The areas of humidity and wreckage submergence are relatively independent of aircraft type and hence there appears to be little reason to change the requirements. For solid-state recorder technology, the humidity requirements are not considered related to crash survivability in any case and are properly covered under the general requirements for humidity given in MIL-E-5400R.

It can be argued that the static crush requirements should also be reviewed. However, the penetration and shock requirements and the test order given dictates a design which easily meets static crush. Even if these latter requirements are relaxed the above would still be the case. Hence, the emphasis in this study is on impact, penetration and fire resistance. A discussion of the tradeoffs and a preliminary analysis follows.

Experience indicate inherent survivability increases as the device is moved rearward in the aircraft. Conversely, for a device having a given design survivabilty, moving the device forward in the aircraft generally results in reduced probability of survival.

TABLE 45. TSO-C51a ENVIRONMENTAL SURVIVABILITY TEST REQUIREMENTS

These environments shall be imposed on a single sample and in the order specified:

1.	Humidity:	Exposure for fifteen(15) twenty-four (24) hour humidity cycles at 95 to 100 percent relative humidity over a temperature range of 38°C to 70°C.
2.	Impact:	The sample shall be exposed to shocks along each of the three (3) main orthogonal axes. The applied shocks shall be half-sine, 1000g's peak with a five (5) millisecond duration.
3.	Penetration:	The sample shall be struck once on each side in the most critical plane with a 500 pound steel bar dropped from a height of ten (10) feet. The point of contact shall be no more than 0.05 square inch. The longitudinal axis of the bar is to be vertical at the moment of impact.
4.	Static Crush:	A force of 5000 pounds shall be applied for five (5) minutes to each of the samples three (3) main orthogonal axes (one axis at a time).
5.	Fire Protection:	The sample shall be exposed to flames of 1100°C enveloping at least half of the outside area for a period of at least thirty (30) minutes.
6.	Water Protection:	The sample shall be immersed in salt water for at least thirty-six (36) hours.

In this study the major tradeoffs are:

(1) Design of a crash survivable memory unit (CSMU) capable of meeting transport category and fighter, attack aircraft requirements for purposes of present and future commonality and hence lower production and logistics cost versus the design of a CSMU specifically for a fighter crash environment. The ensuing discussion and analysis addresses this tradeoff.

(2) Design of a memory module for the most survivable locale on the aircraft (tail section) with the penalty of not having the flexibility to put it in a less survivable location in the future on these or on other aircraft. Since a CSMU that meets TSO-C51a criteria weighs approximately 3.8 pounds, one meeting lesser test criteria would save perhaps one to two pounds and reduce CSFDR hardware cost by 2% or less.

(3) Location of a single-box unit in the EE Bay/Cockpit area with the tradeoff being the favorable cost (initial and life cycle), volume and reliability factors of a one-box approach versus a reduced probability of CSMU survival. This tradeoff is discussed further herein.

Impact Survival

A versed sine curve was chosen to represent the impact acceleration profile as shown in Figure 7. The displacement and velocity versus time curves are shown in Figure 8. Other acceleration curve shapes can be postulated such as a square wave or a sine wave. Both these shapes yield a lower peak value for the same initial velocity and displacement.

A triangular wave may also be postulated. Its calculated peak acceleration would be nearly the same as the versed sine wave profile. The distances to rest assumed are based on typical cockpit area CSMU locations with the unit following the wreckage into a hole to some depth. Figure 7 shows that for distances to rest down to 16 feet or less, the 1000g TSO level is still not exceeded. This would be analogous to some combination of structural collapse and earth deformation over a distance of fifteen (15) feet. This is considered realistic for a CSMU aft-of-cockpit location on a small aircraft such as the F16. In addition, it is estimated that a present CSMU design could withstand g's up to the limits of the solid-state memory device without significantly impacting size and cost. A solid-state CSMU has been successfully tested to 1000g's by Hamilton Standard.

Fire Survival

Under the US Army contract reported in reference (2), Hamilton Standard reviewed in detail the fire resistance test criteria of the referenced TSO. From previous industry studies, it was indicated that a civil jet transport fire burn time is approximately one (1) hour. Obviously this does not confirm the thirty (30) minute flame exposure test in the TSO.

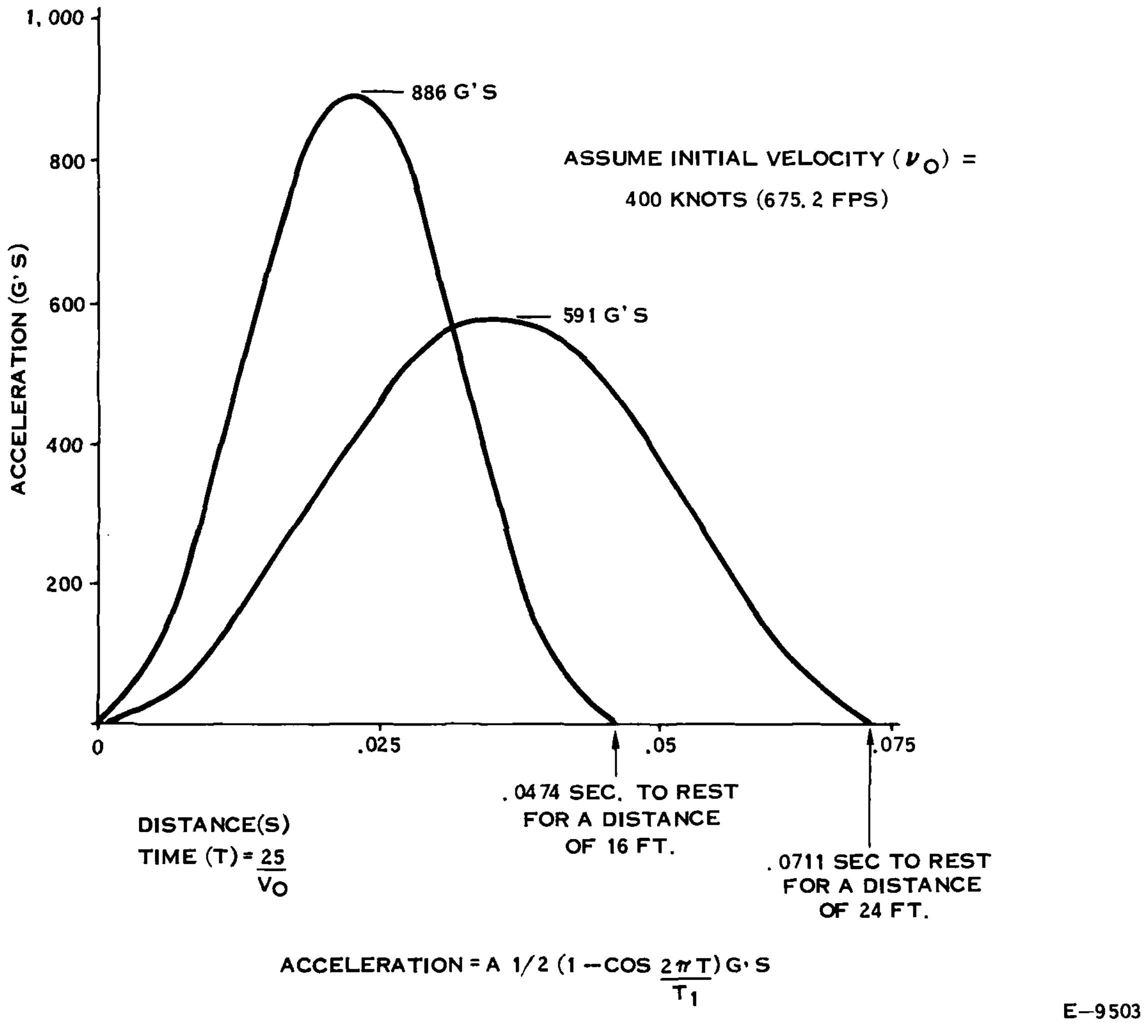


FIGURE 7. IMPACT ACCELERATION PROFILE

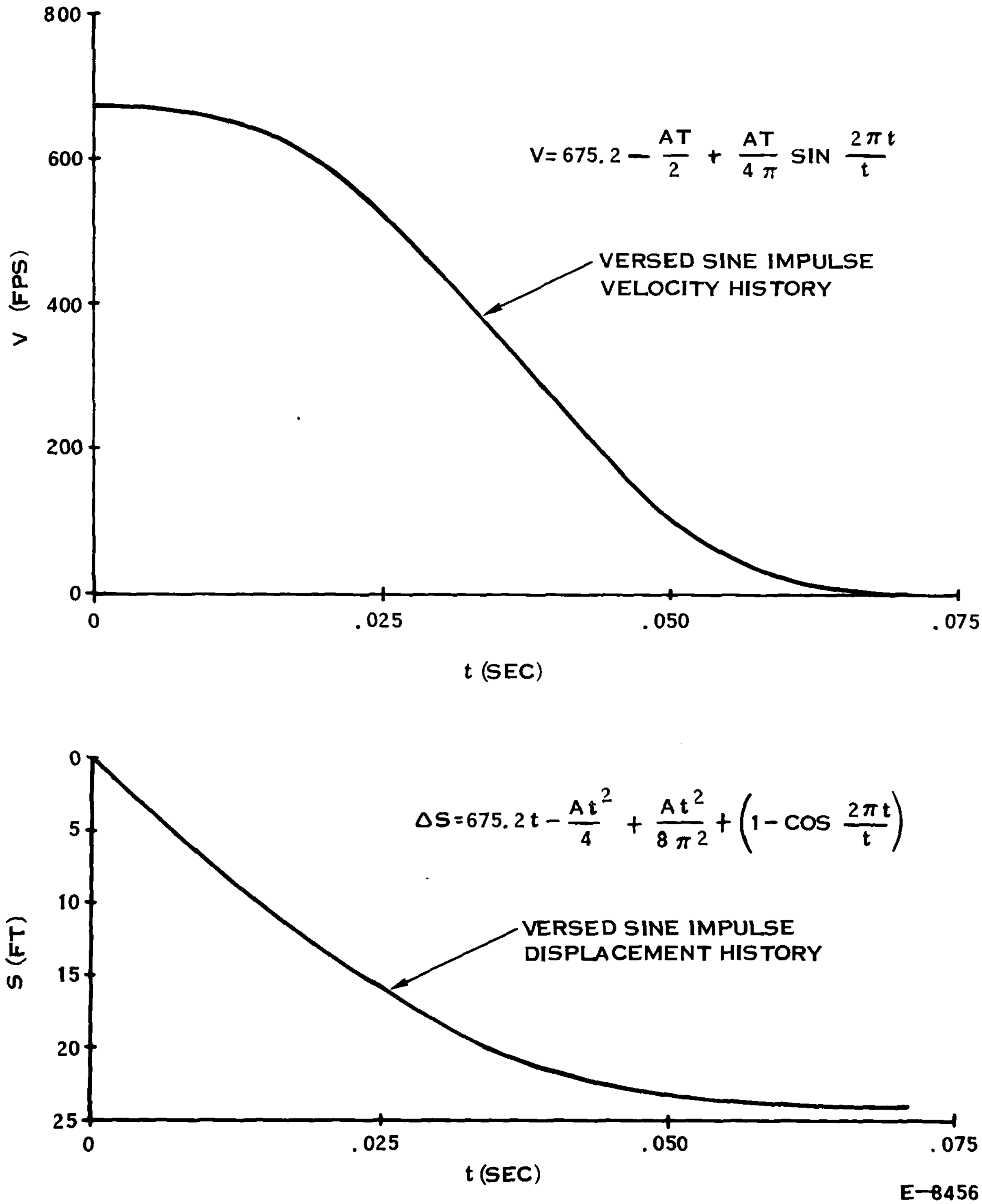


FIGURE 8. VELOCITY/TIME PROFILE FOR IMPACT ACCELERATIONS

The burn or cooling time of an object is a function of the weight to area ratio.

$$t_{B \text{ or } C} = \frac{W}{A} = L = W^{1/3}$$

Therefore, taking into account the fact that the A10 has a 0.439 fuel to weight ratio (Worst case for F15/F16/A10) the following is computed for a fighter weight of 20,000 plus pounds:

$$t_B = \left(\frac{\text{Fighter Wt.}}{\text{Comm. Jet. Wt.}}\right)^{1/3} \left(\frac{\text{Fighter Fuel/Wt.}}{\text{Comm. Jet Fuel/Wt.}}\right) \text{ X 1 Hr}$$

$$t_{BA10} = \left(\frac{20.796}{300.000}\right)^{1/3} \left(\frac{.439}{.500}\right) \text{ X 1 Hr} = .36 \text{ Hr} = 22 \text{ Min}$$

From previous government sponsored studies, it was concluded that a cool down curve that can be approximated by a first order delay time constant of approximately 2 to 3 hours (wreckage temperature down by 63% of its initial value) is typical of a large jet aircraft. Taking the same relationship:

$$t_C = \frac{W}{A} = l = W^{1/3}$$

$$t_C = \left(\frac{\text{Fighter Wt.}}{\text{Comm. Jet. Wt.}}\right)^{1/3} \text{ X 2.5}$$

$$t_C = \left(\frac{20,796}{300,000}\right)^{1/3} \text{ X 2.5} = 1.02 \text{ Hr} = 61 \text{ Minutes}$$

Taking the above calculated values of

Burn Time = 22 minutes and

Cooldown Time = 61 minutes,

the enclosed estimated crash fire profile was generated per Figure 9. Using this curve, the heat absorbed by a CSMU design to provide heat absorbsion by a water boil-off principle is as follows.

Q_B = Heat Absorbed During Burn (BTU)

Q_B = 163 BTU (30 Min @ 2000°F Hamilton Standard Test Data)

$$Q_B = 163 \left(\frac{22 \text{ Min}}{30 \text{ Min}}\right) = 117 \text{ BTU}$$

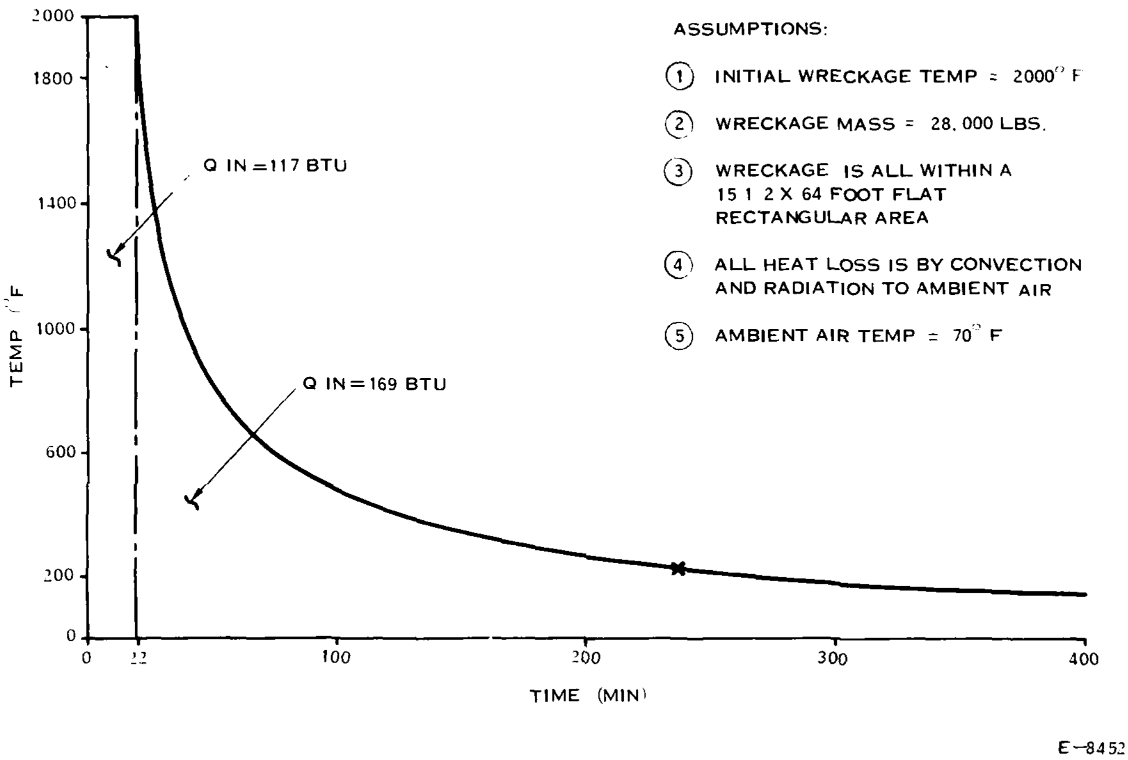


FIGURE 9. ESTIMATED CRASH FIRE PROFILE

Q_C = Heat absorbed during cooldown (BTU)

$Q_C = \int Q\,dt = \int K_{(T)}A\,[T_{(t)} - 212^o]\,dt = 169$ BTU

$Q_{Total} = Q_C + Q_B = 286$ BTU

$Q_{Available}$ = 363 BTU based on .374 lbs of water availabe in a CSMU design as reported in reference (2).

The factor of safety is 363/286 = 1.27 thus indicating that the design for US Army helicopter application is adequate.

PENETRATION SURVIVABILITY CONSIDERATIONS

The existing TSO penetration requirements are considered by Hamilton to be severe, 500 pounds dropped from a height of 10 feet or equivalent to 6.0 ton static load on the specified point contact area of 0.05 inches squared. However, there have been some reported cases in civil transport applications where a survivable enclosure designed to this requirement was penetrated. However, most of the data was recovered in these cases.

The decreased distances that objects can travel within a fighter when they are torn loose are less and the probability is greater that such objects will weigh less while the initial aircraft and object velocities are higher. Therefore, the factors tend to cancel each other.

In the design of a contemporary CSMU, it should be noted that the penetration resistance requirement and the logical order of the specified tests (pentration before flame exposure) does have an effect on CSMU weight with a minor effect on cost and volume. A one pound penalty, or 5% of the total insalled CSFDR system weight could be saved by complete removal of the penetration test if the static crush test segment requirement is ignored. However, it is assumed that some level of penetration resistance need be specified and a lesser structure required for the static crush test in any case. What these lesser design levels should be may be scientifically impossible to arrive at. However, it can be observed that reducing the test mass behind the penetrator from 500 pounds to 250 pounds would result in saving approximately .5 pounds or 2.5% installed system weight. In view of the small increase it is recommended that the test level be maintained.

HUMIDITY, STATIC CRUSH AND WATER IMMERSION SURVIVABILITY CONSIDERATIONS

Humidity

Humidity is not a survivability criteria for solid-state FDRs. It is, however, a general environmental requirement for the total hardware. This requirement is adequately covered by the military avionics specification requirements as noted previously.

Static Crush

Static Crush could be lower for fighter/attack aircraft but is not a design driver. Penertration and impact requirements, even if less severe than the test levels as discussed above, result in a design adequate for the static crush test conditions. It is therefore recommended that the TSO level be retained.

Immersion

Since 10% of Air Force aircraft go down in water, it appears that an immersion requirement is justified. The memory device in a solid-state CSMU will be inherently sealed off from the external normal environment which is expected to be water. The TSO requirement would therefore have no impact on the size, weight or cost.

CSFDR SURVIVABILITY TEST REQUIREMENTS

It is recommended, on the basis of this investigation, that the commonality with the transport category test requirements be maintained at least to the extent of specifying equal or more stringent levels.

By keeping the test levels at the TSO values (more stringent for fire resistance as noted) the CSFDR/CSMU can be placed in any reasonably survivable available location in the aircraft without unduly compromising the system end utility. The flexibility to place the device in any location from the cockpit aft, facilitates the selection of the lowest weight and cost installation on a given aircraft.

2.4 MEMORY TECHNOLOGY EVALUATION

The CSFDR design concept relies on storing digital data in a crash protected solid state memory storage device which is nonvolatile, able to withstand rigorous environmental conditions and provides sufficient data storage capacity for recreation of aircraft flight profiles.

Hamilton Standard has evaluated various nonvolatile solid-state memory devices available in the industry including magnetic bubble memory and Electrically Alterable Read Only Memory (EAROM) devices. A third promising technology in the category of nonvolatile memory systems is the Electrically Eraseable Programmable Read Only Memory (E^2PROM).

The memory technology evaluation concentrated on factors such as:

* Production Availability
* Electrical Characteristics
* Environmental Characteristics

* Complexity

* Cost

Bubble Memory Devices

In 1978, Hamilton Standard procurred and tested bubble devices manufactured by Western Electric and Texas Instruments. The primary thrust of these tests were temperature characterization during operation and under storage conditions. Satisfactory operation was achieved over the range of 0°C to +60°C while data retention over the range of -50°C to +100°C proved satisfactory. The failure of the devices to even approach operation over the full military temperature range negated consideration of these devices in the CSFDR concept in the near term. Western Electric did indicate confidence that, with additional development effort and time, a mil temperature device could be achieved.

During the latter part of 1978, Rockwell performed extended temperature testing of a 256K bit device (RBM 256). Experiments with bias field and drive field changes were accomplished to compensate somewhat for changes in temperature. Their current devices were found to operate over a temperature range of -25°C to +75°C. Rockwell reported gaining valuable information that could lead to improved bubble memories and "---eventual militarization of the bubble device".

During this same period, Texas Instruments published a report discussing the effects of temperature on TI's 254K bit magnetic bubble memory device. The nominal operating temperature range was found to be -25°C to +75°C with a storage temperature range of -50°C to +110°C. TI indicated that there were several areas which were being examined in order to expand the temperature limits of the device and indicated that the possibility exists that a mil-temperataure device could be developed in the mid 1980's. This stance has since been revised.

The potentially large market for bubble memory devices, especially in the commercial market, has prompted several other manufacturers to invest development time and money in this technology. INTEL Corporation has two 1 megabit devices which differ from the Western Electric, TI and Rockwell devices only in their frequency of operation. National Semiconductor will have a 256K bit bubble device in full production by mid 1981 and will also be working on a 1-megabit device. Motorola is second sourcing Rockwell's 256K bit device (already in production at Rockwell) and will be sampled by Motorola in late 1980. Both Rockwell and Motorola are working on a 1-megabit bubble device but as yet have no compatibility agreements. Rockwell's 256K and 1-megabit device will be interchangeable.

Western Electric is presently in production with a 256K bit serial loop device and is presently working on a 250K bit major/minor loop bubble memory.

Texas Instruments has the largest family of devices including 1-megabit, 500K bit and 250K bit bubbles which are interchangeable with 92K bit device tested by Hamilton Standard in 1978.

EAROMS

Electrically Alterable Read Only Memories (EAROM's) are solid-state nonvolatile memory devices. They can be in-circuit programmed or erased. The memory element is the metal-nitride-oxide-semiconductor (MNOS) transistor. It is a basic MOS transistor which has had the gate oxide layer replaced by a silicon dioxide-silicon nitride sandwich. The silicon dioxide is made 25 angstroms (Å) thick to allow charge to tunnel through at gate voltages of 25 to 30V. When electrons tunnel through the oxide layer they become trapped at the nitride-oxide interface which alters the threshold of the device. The transistor can then be read to determine the logic level stored.

Westinghouse makes several Block Oriented Random Access Memories (BORAM's). They are a 2K and an 8K bit chip with 32K and 131K bit chips one (1) to two (2) years away. Westinghouse packages these in hybrids which can house up to sixteen (16) chips. Sperry Univac also has an 8K BORAM available and is looking into manufacturing a 65K device.

Nitron, General Instruments (GI), and National Cash Register (NCR) have 1K X 4 and 2K X 4 EAROM's available; however, all of their 2K X 4 devices are difficult to interface because of the necessity of pulsed power supplies. Seimans has a 1K X 8 device which also uses pulsed power supplies and may look at larger devices in the future. All of the aforementioned EAROM's have storage temperature ranges of -55 to 125°C. NCR's devices would require outside screening to achieve the above temperature range. NCR, GI and Nitron are willing to sell dies to be placed in a hybrid; however, the dies would not have been tested over the entire mil temperature ranges. GI and Nitron expressed an interest in building a tested hybrid.

MNOS EAROM memories have a limited lifetime as a result of degradation of the nitride film during write cycles. These devices currently are limited to 10^5 erase-write cycles per word. Some device manufacturers are now claiming further improvements to 10^6 cycles and higher. However, in the CSFDR application, an average erase-write cycle would occur less than twice per location per hour thus providing a memory lifetime in the tens of thousands of operating hours.

Hamilton Standard used the Westinghouse 32K bit hybrid BORAM for Phase I and II AIRS testing while independently developing a 32K bit hybrid device using both NCR's 2451 (4K) chips and GI's ER3400 (4K) chips.

The hybrid circuit developed by Hamilton Standard has advantages of requiring less support circuitry for operation while providing a simplified interface in comparison to the Westinghouse BORAM unit. The areas of simplification include direct parallel input of data in lieu of parallel to serial conversion in the BORAM, direct read/write capability in comparison to the block data read/write (256 bits) in the BORAM, no level conversions whereas BORAM requires TTL to CMOS level conversions. The results of this simplified operation affords a 50% reduction in support hardware requirements and an attendant lower cost.

E^2PROM

Electrically Eraseable Programmable Read Only Memories (E^2PROM's) are also solid-state nonvolatile memory devices. Their construction differs from EAROM's in that they use a floating gate MNOS transistor as the data storage element. E^2PROM's have a thicker oxide layer, 200Å versus 25Å for EAROM's, causing stored charge to leak off slower than in the EAROM. The transistor consists of a thin oxide layer separating the P-well from the polysilicon floating gate and a nitride/oxide layer separating the floating gate from the control gate (higher device). Data is stored by causing electrons to tunnel into and out of the floating gate structure. The nitride/oxide sandwich ensures strong capacitive coupling between the two gate structures so lower voltages can be used for earasing and writing.

Motorola has a 2K X 8 device and will be sampling a 4K X 8 E^2PROM in mid-1981. INTEL will be sampling a 2K X 8 device in the next few months. Hughes offers a 1K X 8 and 1K X 4 CMOS devices, but both require pulsed power supplies. Hitachi has a 2K X 8 device which also requires a pulsed program voltage. XICOR has a 1K X 1 E^2PROM and is the only company offering a standard Random Access Memory (RAM) array with a shadow E^2PROM section. Ten milliseconds is required for the entire contents of RAM to be programmed into the nonvolatile E^2PROM section. A T^2L signal and 1.5 µs is all that is required to move the E^2PROM contents back into RAM. XICOR will be sampling a 1K X 4 device in 1981.

SUMMARY OF DEVICE CHARACTERISTICS

BUBBLE MEMORIES

Capacity

The largest bubble device available contains a one (1) megabit memory and is produced by both INTEL (two versions) and Texas Instruments. Rockwell will be sampling a 1 megabit device later this year while Motorola plans to be sampling theirs in 1981. Texas Instruments makes a 1/2 megabit and 1/4 megabit device, both of which are interchangeable with the one (1) megabit bubble and a 92K bit bubble. National Semiconductor, Rockwell, Motorola and Hitachi each have a 1/4 megabit device while Western Electric has a 272K bit serial bubble and is working on a 250K major/minor loop device. Hitachi plans one (1) and four (4) megabit devices to be available sometime in late 1982 or early 1983.

Interface Requirements

All bubble devices require extensive interface circuitry. The manufacturers are all developing their own custom integrated control chips.

Power

Power requirements of the bubble memories themselves range from 450 milliwatts for the Hitachi 64k bit device to 1.9 watts for each of the two INTEL bubbles.

Voltage requirements were not available for the Hitachi bubble memories. Western Electric requires +5V DC and $\pm$ 15V DC for the 272K bit device and +5V DC and $\pm$ 12V DC for the 250K bit device. Motorola, National Semiconductor and INTEL use +5V DC and +12V DC while Texas Instruments and Rockwell use +5V DC and $\pm$ 12V DC.

Access Times

Bubble write times are dependent upon frequency of operation. INTELs write time is typically 117μs/8 bits for their 7110 and 58.4μs/8 bits for the 7112. National Semiconductor takes 80μs/8 bits for their 256K device while TI requires approximately 80μs/8 bits for their 1 megabit device. Rockwell's 256K device write time is 52.8μs/8 bits. Write time for their 1 megabit bubble was not available. Motorola is a second source for the Rockwell RBM 256 and timing information for the 1 megabit part was not available.

Temperature Range

Temperature ranges are a serious drawback for current bubble memory technology. Operating ranges are on the order of 0°C to 70°C with the largest storage temperature range being -50°C to 100°C claimed by Rockwell and Motorola.

EAROM's

Capacity

Westinghouse makes the highest density family of devices ranging from 2K and 8K bits/chip with 32K and 131K bits/chip planned for 1981/1982. Sperry Univac currently has an 8K BORAM while General Instrument, NCR, and Nitron have 8K and 4K EAROM's available.

Interface Requirements

The Westinghouse and Sperry Univac BORAM devices require a considerable amount of interface circuitry for timing and signal voltage level control. All of the 8K EAROM's are also difficult to interface because they require the power supplies to be pulsed during a write or erase operation. The 4K devices from GI, NCR and Nitron are the easiest to interface since they are static, T^2L compatible devices (with resistor pull-ups) and do not require pulsed power supplies.

Power

The Westinghouse BORAM's dissipate the least amount of power, typically 375 mw for the 2K and 8K devices. The 4K devices from Nitron and NCR require approximately 400 mw while the 4K EAROM from GI dissipates about 570 mw. The GI, NCR and Nitron 8K EAROM's dissipate the most power, typically 650 mw.

All of the above mentioned EAROM's require multiple power supplies, from two for the Sperry Univac device to four necessary to operate the GI, NCR, Nitron and Seimans 8K devices. The 4K EAROM's require three power supplies each as do the family of Westinghouse BORAM's.

Temperature Range

All devices surveyed will store data from -55°C to at least 125°C. Only NCR and Nitron had operating ranges of 0-70°C while the others are rated at -55°C to 125°C.

Access Times

The Seimans 8K device is the slowest taking one (1) second to chip erase and 10-20 ms/word to write. The same manufacturers 4K devices require 10 ms to word or chip erase and only 1 ms/word to write data. The Westinghouse BORAM's take on the order of 236μs to write 32 bits and 1 ms to chip erase. Sperry Univac specifies typically 500μs to write and 500μs to erase a block of data.

Only GI and Sperry Univac plan to develop larger devices.

E^2PROMS

Capacity

The largest E^2PROM contains 32K bits and is presently being developed by Motorola. They also offer a 16K device along with INTEL and Hitachi. Hughes presently has an 8K and a 4K CMOS E^2PROM "shadow" area, available as a 1K X 1 part. INTEL and Motorola have no plans to develop larger devices.

Power

The Hitachi and both Hughes E^2PROM's require power supply packing. All others are static devices.

The INTEL E^2PROM dissipates 500 mw, the highest value of the group. Hitachi is next with 300 mw, XICOR with 200 mw and the Hughes CMOS devices require the least; 170 mw. Power dissipation figures for the two Motorola devices were not available.

All devices except XICOR's 1K X 1 require two power supplies +5V DC and +17V DC to +25V DC. The XICOR chip requires only +5V DC.

Temperature Range

Temperature range information was not available for the INTEL chip or the Motorola 32K device. Motorola's 16K chip has an operating range of -10°C to 85°C. A storage temperature range was not available. Both XICOR and Hitachi

parts operate at 0-70°C. Only Hughes offers an operating temperature range of -55°C to 125°C. The storage temperature range for the Hughes, XICOR and Hitachi devices is -65°C to 125°C.

Access Time

Write and erase times for the Motorola 32K and the INTEL E^2PROM were not available. The Hughest CMOS chips are the fastest requiring only 100μs/8 bits to write and 100μs to byte or chip erase. XICOR is next taking 10 ms to write the RAM half of memory into the E^2PROM half. Hitachi takes 1 sec to erase the entire chip while taking only 800μs to program 8 bits. The Motorola chip takes 50 ms to chip erase and 10 ms/byte write time.

BUBBLE MEMORIES DEVICE TECHNOLOGY

SUMMARY (Reference Tables 46 and 47)

Current

* Multiple sources - however, current industry emphasis is on commercial applications.

* One manufacturer claims -10 to 70°C operation. Most are 0 to 70°C storage temperature range -40 to 100°C or -30 to 120°C depending on maker.

* Highest memory capacity per unit size.

* Not suitable for military avionics.

Far Term

* Higher operational temperatures expected but will require changes in basic device design.

* Very high bit capacities in future would allow significant parameter expansion and functional integration with other recording needs.

EAROM MEMORY DEVICE TECHNOLOGY

SUMMARY (Reference Table 48)

Current

* Multiple sources

* Meets full military operational temperatures -55 to +125°C.

* Some devices can store data up to 165°C.

* Memory capacity per unit volume and operating speeds are suitable for the CSFDR application.

TABLE 46. BUBBLE MEMORY TECHNOLOGY STATUS (11/6/80)

VENDOR	PART NUMBER	STORAGE CAPACITY (IN BITS)	DESIGN	ELECTRICAL CHARACTERISTICS			TEMPERATURE CHARACTERISTICS		SIZE (IN INCHES)	I/O PINS	AVAIL-ABILITY	COST
				ACCESS TIME	VOLTAGES REQUIRED	POWER DIS-SIPATION	OPERATING	STORAGE				
Texas Instruments (Note 1)	TIB 1000	1MEG	--	11.2MS	+5, ± 12	1.2W	0^0C to 70^0C	-40^0C to $+85^0C$	1.1x1.4x0.4	24	4 Wks	$200 in 1981
	TIB-0500	1/2MEG	Page Swap/ Replicate	11.2MS	+5, ± 12	1.2W	0^0C to 70^0C	-40^0C to $+85^0C$	1.1x1.4x0.4	24	4 Wks	$125 in 1981
	TIB-0250	1/4MEG	Page Swap/ Replicate	6.1MS	+5, ± 12	1.2W	0^0C to 70^0C	-40^0C to $+85^0C$	1.1x1.4x0.4	24	4 Wks	$100 in 1981
	TIB-0203	92K	Major/Minor	4MS	+5, ± 12	0.7W	0^0C to 70^0C	-40^0C to $+85^0C$	1.1x1.4x0.4	14	4 Wks	$50 now
Intel (Note 2)	7110	1MEG	Block Replicate 512 Bit Page/2048 Pages	40MS (60 KHZ Nom. Data Rate)	+5, + 12	1.9W	0^0C to 70^0C -20^0C to 85^0C Future Poss.	-40^0C to $+100^0C$	1.5x1.7x0.5	20	Now	$2,195 with Proto-board
	7112	1MEG	Block Replicate	20MS (136 KHZ Nom Data Rate)	+5, + 12	1.9W	0^0 to $+50^0C$	-40^0C to $+100^0C$	1.5x1.7x0.5	20	1981	Unknown
National Semi-Conductor (Note 3)	NBM2256	256K	Major/Minor 256 x 1024	7MS	+5, +12	Unknown	0^0C to $+70^0C$	-40^0C to $+100^0C$	1.1x1.02x0.34	Unknown	Full Prod Mid 1981	$500
	- -	1MEG	Major/Minor	1st 16 Bytes write every 10µs 80 µs/word thereafter	+5, +12	Unknown	0^0C to $+70^0C$	-40^0C to $+100^0C$	1.1x1.02x0.34	Unknown	≈Mid 1981	Unknown
Rockwell (Note 4)	RBM256	256K	260 loops x 1024 bits	4MS	+5, ±12	1W	-10^0C to $+70^0C$	-50^0C to $+100^0C$	1.2x1.2	18	In Pro-duction	$410
	RBM411	1MEG	Unknown	Unknown	Unknown	Unknown	-10^0C to $+70^0C$	-50^0C to $+100^0C$	1.2x1.2	18	DEC 1980	$1,455

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TABLE 47. BUBBLE MEMORY TECHNOLOGY STATUS (CONTINUED)

VENDOR	PART NUMBER	STORAGE CAPACITY (IN BITS)	DESIGN	ELECTRICAL CHARACTERISTICS			TEMPERATURE CHARACTERISTICS		SIZE (IN INCHES)	I/O PINS	AVAIL-ABILITY	COST
				ACCESS TIME	VOLTAGES REQUIRED	POWER DISSIPATION	OPERATING	STORAGE				
Motorola (Note 5)	RBM256	256K	260 Loops x 1024 bits	4MS	+5, ± 12	1W	$-10^{o}C$ to $+70^{o}C$	$-50^{o}C$ to $+100^{o}C$	1.2 x 1.2	18	Sampling now	$500
	MBM1000	1MEG	Major/Minor	10MS	Unknown	Unknown	$0^{o}C$ to $+50^{o}C$	$-30^{o}C$ to $+100^{o}C$	Unknown	Un-known	Sampling in 1981	Unknown
Western Electric (Note 6)	- - -	272K	(4)68K bit loops	650MS	+5, ± 15	1W	$0^{o}C$ to $+70^{o}C$ ($-30^{o}C$ to $+60^{o}C$)	$-40^{o}C$ to $+80^{o}C$ ($-30^{o}C$ to $+120^{o}C$)	1.2x2.5x0.7	Un-known	Now	Unknown
	29C	250K	Major/Minor	6MS	+5, ± 12	800MW	$0^{o}C$ to $+60^{o}C$	$-40^{o}C$ to $+85^{o}C$	1.5x2.0x0.6	Un-known	Unknown	Unknown
Hitachi (Note 7)	BDG0101	64K	128 Loops x 535 Bits	5MS	Unknown	450MW	$0^{o}C$ to $+50^{o}C$	$-40^{o}C$ to $+85^{o}C$	Unknown	18	Unknown	Unknown
	H4701B	256K	256 Loops x 1135 Bits	7MS	Unknown	800MW	$0^{o}C$ to $+50^{o}C$	$-40^{o}C$ to $+85^{o}C$	1.0x1.0x0.5	20	Unknown	Unknown

NOTES:

1. T/I does not expect mil-temperature bubbles before 1982. TI 1 MEG device has 34 BYTE page only, 92K device has 18 BYTE page only. After page is written in either device, it takes 80 micro-seconds to write 8 Bits. All devices are interfaced by six (6) custom integrated circuit devices.
2. Intel does not foresee a mil-temperature device. The 7110 One MEG devices employ 40 x 8 FIFO writes at 1.6 μs/8 bits @4 MHZ. Thereafter, writes at 117 μs/word. The 7112 one MEG device operates at 117 μs/8bits to bubble. Both devices are interfaced by six (6) custom integrated circuit devices.
3. First 16 bits are written every 10 μs, thereafter writes at 80 μs/word. Bubble is paralleling with an external shift register. NS does not plan to develop a mil temperature device. NS interfaces the device with 5 custom large scale integration (LSI) devices.
4. Both the 256K and 1 MEG devices are interchangeable. Rockwell is not planning a mil temperature device. Rockwell is presently designing custom LSI devices to interface the bubble memories.
5. Motorola is second source for Rockwell 256K device. The Motorola 1 MEG device is not interchangeable with the 256K device and they do not have agreement for second source to Rockwell. Motorola will use custom controller being developed by Rockwell plus other custom LSI's being developed by Motorola to interface to bubbles.
6. W.E. uses one 8 1/2 x 11 controller board and one 8 1/2 x 11 bubble board to form complete system for 272K device. Presently developing custom LSI's for 250K devices. WE is also looking at larger devices.
7. Hitachi is not selling the 64K device because of interest in 256K device. They plan to start work in 1981 on a 1 MEG device and will have a 4 MEG device in the 1982-1983 time frame for which they are looking for second source. Interface to all devices will be custom designed integrated circuits.

TABLE 48. EAROM/BORAM TECHNOLOGY STATUS (11/6/80)

VENDOR	PART NUMBER	STORAGE CAPACITY (IN BITS)	DESIGN	ELECTRICAL CHARACTERISTICS: ACCESS TIME	ELECTRICAL CHARACTERISTICS: READ/WRITE CYCLES	ELECTRICAL CHARACTERISTICS: VOLTAGES REQUIRED	ELECTRICAL CHARACTERISTICS: POWER DISSIPATION	TEMPERATURE CHARACTERISTICS: OPERATING	TEMPERATURE CHARACTERISTICS: STORAGE	I/O PINS	AVAILABILITY	COST	INTERFACE COMPLEXITY
General Instruments (Note 1)	3400	4096	1024x4	12MS	10^5	+5,-12,-30	570MW	-55°C to +125°C	-55°C to +125°C	22	Off the Shelf	$36.56	- - -
	2810	8192	2048x4	110MS	10^5	±5,-14,-24	650MW	-55°C to +125°C	-55°C to +125°C	24	2 to 3 weeks	$39.74	Pulsed power supplies
Nitron (Note 2)	7810	8192	2048x4	110MS	10^5	±5,-14,-23	650MW	-55°C to +125°C	-55°C to +125°C	24	2 to 4 weeks	$21.85	Pulsed power supplies
	7451	4096	1024x4	12MS	10^5	+5,-12,-30	>400MW Deselected	-55°C to+125°C	-55°C to+125°C	22	4th Qtr 1981	$17.25	- - -
National Cash Register (Note 3)	2451	4096	1024x4	12MS	10^5	+5,-12,-30	458MW	0°C to 70°C	-55°C to+125°C	22	8 to 10 weeks	$22.00	- - -
	2810	8192	2048x4	125MS	10^6	±5,-14,-23	650MW	0°C to 70°C	-55°C to+125°C	24	8 to 10 weeks	$25.00	Pulsed power supplies
	2401	4096	1024x4	120MS	10^6	+5,-15,-23	>400MW	0°C to 70°C	-55°C to+125°C	24	16 to 20 weeks	$18.00	Pulsed power supplies
Seimans	SAB2808	8192	1024x8	60sec erase 50MS write	10^3	±5,+12,+33, +25	400MW	0°C to 70°C	Unknown	24	Unknown	Unknown	Pulsed power supplies
Westinghouse (Note 4)	6002C	2048	64x32	5 μs	10^5	±5,+5,-20	<375MW	-55°C to+125°C	-65°C to+150°C	24 (Hybrid)	12 to 15 weeks	$3K/System	4.5x5.5 P.C. Card
	6008	8192	64x128	5 μs	10^5	±5,+5,-20	<375MW	-55°C to+125°C	-65°C to+150°C	24 (Hybrid)	12 to 15 weeks	$3.7K/System	4.5x5.5 P.C. Card
	6032	32K	250x128	10 μs	10^5	±5,+5,-20	Unknown	-55°C to+125°C	-65°C to+150°C	24 (Hybrid)	1 Year	Unknown	4.5x5.5 P.C. Card
	6131	131K	1024x128	10 μs	10^5	±5,+5,-20	Unknown	-55°C to+125°C	-65°C to+150°C	24 (Hybrid)	2 Years	Unknown	4.5x5.5 P.C. Card
Sperry Univac (Note 5)	[illegible]	[illegible]	256x32	500 μs Write 500 μs Read	Unknown	+12,-18	500MW/Write	-55°C to+125°C	-55°C to+125°C	16 (Flat Pack)	In Test	Unknown	Pulsed control signal

NOTES:

1. The [illegible] is block erase only. GI planning larger and faster N-channel devices, would prefer to sell hybrids rather than dies.
2. The 7451 is presently in the R&D stage. Not planning any larger devices. Will sell dies tested to room temperature and will consider possibility of selling hybridized devices.
3. Parts may be screened to operate from -55° to +125°C (possible but not probable). Will sell dies; not planning larger devices.
4. Will not sell dies and are reluctant to sell basic BORAM device (hybrid units). Westinghouse is working on a smaller package with same pinout arrangements. Also, access time is from stable data to first bit.
5. Will not sell dies but will sell hybrid. Planning a 65K device at the very least, possibly higher.

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Far Term

* Further increases in chip densities are expected.

* Chip bit densities are expected to increase by at least 8X in the mid nineteen eighties.

E^2PROM MEMORY DEVICE TECHNOLOGY

SUMMARY (Reference Table 49)

Current

* Multiple sources

* Meets military operational temperatures -55 to 125^{o}C.

* Quiescent storage capability expected to be comparable to EAROM's.

* Memory capacity per unit volume comparable to EAROM's - suitable for CSFDR application.

* Operational erase/write speeds marginal but acceptable for current requirements.

Far Term

* Operational speeds may limit future applications.

* Future bit densities are expected to follow EAROM's.

2.5 DATA PROCESSING/COMPRESSION

Microprocessor Technology

The capacity is readily available in today's technology processor to accomplish the CSFDR airborne processing for data compression and storage. The Intel 8085 has been demonstrated to have the capacity, with over 100% reserve, in performing flight data recorder applications. Ten (10) times the processing is expected to be available in future microprocessors.

Data Compression Technology

Data compression technology has a major impact on the size, weight and cost of a CSFDR. The data compression methods for a given set of signal fidelity requirements and recording time will determine the crash survivable memory size. Hamilton Standard has conducted data compression studies on military helicopters, commercial airlines and military fighter/attack aircraft in order to determine the effectiveness of various data compression techniques.

TABLE 49. E^2 PROM TECHNOLOGY STATUS (11/6/80)

				ELECTRICAL CHARACTERISTICS				TEMPERATURE CHARACTERISTICS					
VENDOR	PART NUMBER	STORAGE CAPACITY (IN BITS)	DESIGN	ACCESS TIME	READ/ WRITE CYCLES	VOLTAGES REQUIRED	POWER DIS-SIPATION	OPERATING	STORAGE	I/O PINS	AVAIL-ABILITY	COST	INTERFACE COMPLEXITY
HUGHES (Note 1)	HNOVM 3004	4096	1024x4	200 μs	10^5	+5,+17	170MW, Max	-55°C to +125°C	-65°C to +125°C	24	Off the shelf	$200	Pulsed power supplies
	HNOXM 3008	8192	1024x8	200 μs	10^5	+5,+17	170MW, Max	-55°C to +125°C	-65°C to +125°C	24	Off the shelf	$400	Pulsed power supplies
Motorola (Note 2)	2816	16K	2048x8	Block Erase @50 μs Write @10MS	10^5	Unknown	Unknown	Unknown	Unknown	Un-known	1981 Pro-duction	$25	- - -
	- - -	32K	4096x8	Unknown	10^5	Unknown	Unknown	Unknown	Unknown	Un-known	Sample mid 1981	Un-known	- - -
Intel (Note 3)	2816	16K	2048x8	Unknown	10^4	+5,+20	500MW	Unknown	Unknown	Un-known	Sample 30-60 days	Expen-sive	- - -
XICOR (Note 4)	X2201	1024	1024x1	10MS Array Write	Unknown	+5	200MW	0 to +70°C (Note 5)	-65°C to +125°C	18	Now	$75	- - -
Hitachi (Note 6)	48016	16K	2048x8	1 sec Erase 8 μs Write	10^3 to 10^5	+5,+25	300MW	0 to 70°C	-65°C to +125°C	24	2-3 Weeks	Unknown	Pulsed pro-gram voltage

NOTES:

1. Hughes is willing to sell dies but not temperature tested. Planning larger devices (32K E^2 PROM) for third quarter 1981 plus a 32K EAROM later; both devices are CMOS.
2. Motorola is willing to sell dies tested only at 25°C. Presently looking at mil-temperature devices.
3. Intel is willing to sell dies and are looking for second source. Devices will be single byte erasable.
4. XICOR would prefer to sell hybrid rather than dies. Are considering larger (1K x 4) device in 1981.
5. RAM and recall operates at mil temperature; however, data storage into E^2PROM is a problem at mil temperatures.
6. Hitachi will not sell dies. The device chip erase is compatible with 2716.

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AD-A098 584 UNITED TECHNOLOGIES CORP WINDSOR LOCKS CT HAMILTON ST--ETC F/G 1/4
REQUIREMENTS, TECHNOLOGY AND CONFIGURATION EVALUATION FOR CRASH--ETC(U)
APR 81 H R ASK, J A HERNDON, D L WHITE F33615-80-E-0134
UNCLASSIFIED ESP-8111 ASD-TR-81-5010 NL

2 OF 3
AD A
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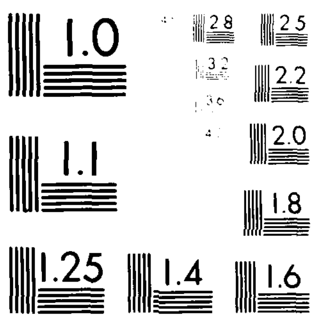


MICROCOPY RESOLUTION TEST CHART

The object of data compression is to optimize the amount of information contained in a fixed number of memory bits to take advantage of solid-state memory technology and its attendant benefits. The advantage of data compression can be seen by viewing the investigation problem backward in time from the mishap. In the last few seconds, it is likely that many of the parameters are changing rapidly and essentially continuous recording of data is desired. This data will usually give a detailed account of what happened in the mishap itself. However, this data might not give the basic root cause of the mishap or the conditions that led to the mishap. If the system records data at a continuous rate, it will not be possible to record very far back in time in consideration of limited-cost systems. In the flight up to the mishap, it is likely that many parameters will change only slowly or remain essentially constant. Thus, if the recording is constant, much of the data is repetitive and does not add any additional information. The object of the data compression process is to eliminate the redundant data in order to allow the essential data to be retained much farther back in time from the mishap. The goal is to record basic data for at least fifteen (15) minutes prior to the mishap.

The following paragraphs describe the data compression techniques studied. The approach taken in this presentation is to first describe the fundamental compression procedure proposed and then describe in more detail the alternative implementations and variations of this basic procedure. The advantage and disadvantages of each specific technique are discussed and the effectiveness of each is evaluated. The effectiveness is determined by the use of actual data available from actual flight evaluations and flight simulation evaluations.

Floating Limit Data Compression Procedure

The basic data compression philosophy, which is fundamental to the specific techniques studied, is based on the concept of a floating limit. Much data storage space is wasted by continuing to record a parameter that is not changing or is changing very slowly. The floating limit technique eliminates this redundant data by saving the last recorded value of a parameter and only recording it again if it changes from the last value by more than some specified limit. A typical example of the application of floating limits is shown in Figure 10, taken from actual flight data using a wide limit to show the effect of the wide limit on the reconstruction. The size of the limit will be a tradeoff between the accuracy desired for the recorded parameter and amount of compression achieved.

The example shown has a relatively large limit to clearly illustrate the floating limit concept. The limit can be made smaller such that on a plot like Figure 10, the two curves would be almost indistinguishable while providing a large degree of data compression.

The floating limit selective recording process is illustrated in Figure 11. In the illustration, a sample of all parametric data is saved at fixed periods. When data is saved, a plus and minus limit range is defined about the saved value. As long as new data samples fall within the established

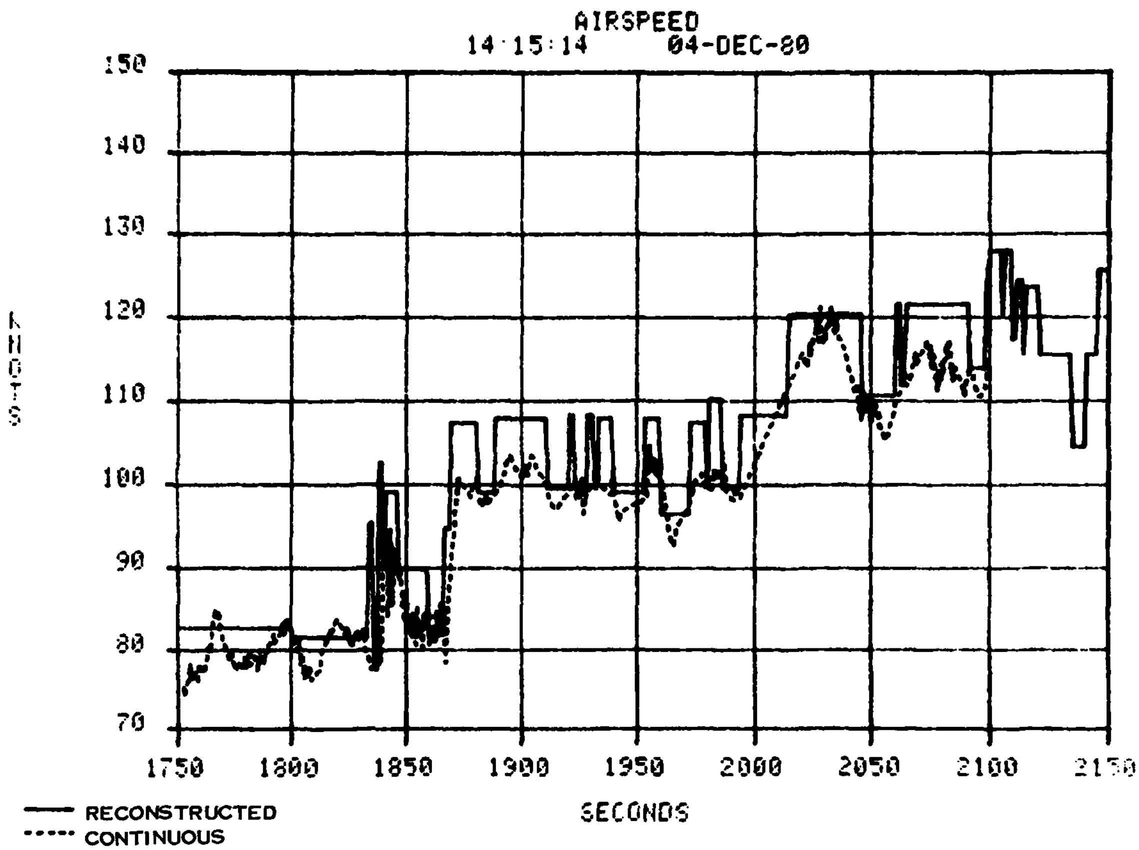


FIGURE 10. TYPICAL EXAMPLE OF FLOATING LIMIT RECORDING

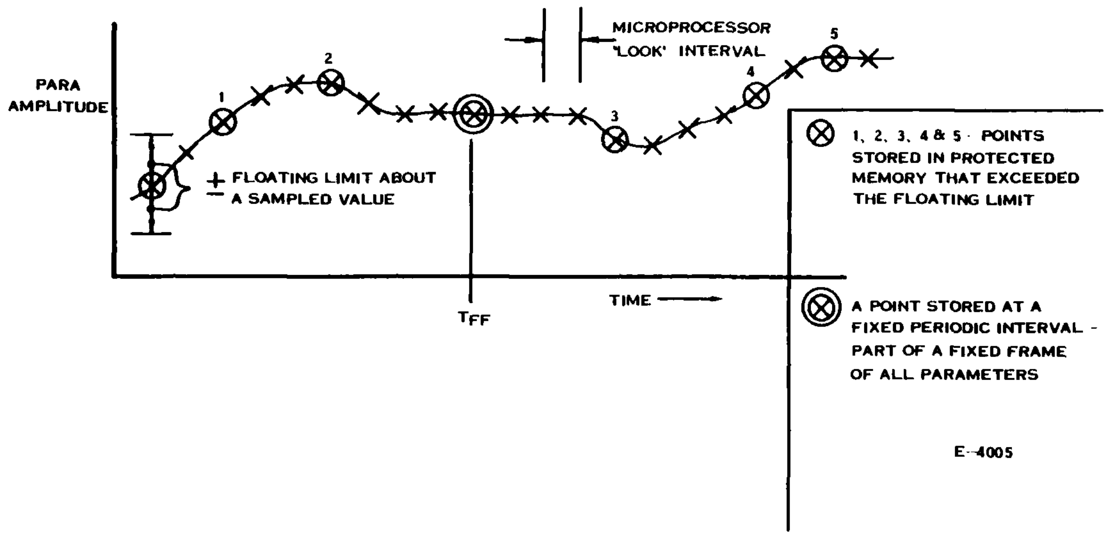


FIGURE 11. CSFDR SELECTIVE RECORDING PROCESS

range no further data is saved between the periodic data; however, if a sample mxceeds the defined range, a new data point is saved and limits are set around the new data point. Between fixed period samples, only exceedance data is stored.

Several factors must be considered in the development of the floating limit data compression techniques. Two major considerations are the choice of the floating limit and the organization of the data in the memory.

Size of the Floating Limit

The size of the floating limit is basically a function of the requirements set by the investigators to allow adequate fault investigation procedures. The basic values assumed for the limits were determined by discussion with accident investigation personnel. These basic limits are shown in Table 50. These limits were used as a reference and the effects of variations in these limits were evaluated both in terms of the accuracy of following the actual signal and amount of compression. This evaluation has been performed on the parameter in a number of flight test and simulation programs.

Examples of altitude, roll attitude, engine rpm and fuel flow raw data and floating limit data, are both plotted together as shown in Figures 12 through 15. The reproductive accuracy varies based on the size of the limits.

The effect of changing the limit exceedance value on the quantity of data stored is shown in Figure 16. The wider the limits, the lower the quantity of data recorded and thus the lower the reproduction accuracy. As the limits are reduced, more data is stored increasing the fidelity of the data until storage requirements start to rise rapidly due to noise in the sensors and the system.

Sampling Rate

Another important consideration that is clearly related to limit size is sampling rate. The maximum sample interval that is considered acceptable is given in Table 50. When floating limits are used, a significant measure of the adequacy of the sample rate is the maximum rate of the parameter in terms of limit values per sample. For example, if altitude has a 50-foot limit, a 3000 ft/min vertical speed will have a one limit per sample rate at one sample per second. If the vertical rate is greater than 3000 ft/min, the uncertainty in the altitude between samples will be greater rates in terms of limit values per sample interval.

Memory Structure

The memory organization affects the structuring of data and overhead. If a serial memory is used, sync words are required to identify the beginning of data. These sync words can be identified by the frame type. The serial structure allows a very efficient packing of data by allowing data dependent frame lengths with the overhead primarily in the sync words. If an addressable memory is used, it can be structured in blocks allowing fixed location for frame type.

TABLE 50. RECORDER PARAMETER LIMITS

PARAMETER	SAMPLE INTERVAL (IN SEC)	CHANGE REQUIRED FOR RECORDING	RECORDING RESOLUTION	NOTES
Calibrated Airspeed	1	10 Knots	5 Knots	
Altitude (Barometric)	0.25	50 Feet	35 Feet	
Sink Rate Vertical Velocity				Derive From Altitude
Pitch Attitude	0.25	4 Degrees	2 Degrees	
Pitch Rate				Derive From Pitch Attitude
Bank Angle (Roll Attiude)	0.25	4 Degrees	2 Degrees	
Roll Rate				Derive From Roll Attitude
Normal Load Factor (Vertical G's)	0.25	0.2 G	0.1 G	
Heading	0.25	2 Degrees	1 Degree	
Yaw Rate				Derive From Heading
Angle of Attack	1	2 Degrees	1 Degree	
Mach	1	0.04 M	0.02 M	
Side Slip Angle	1	2 Degrees	1.0 Degree	
Speed Brake	1	8%	4%	
Flight Controls				
Aileron Position	1	2 Degrees	1 Degree	
Elevator Position	1	2 Degrees	1 Degree	
Rudder Position	1	2 Degrees	1 Degree	
Stick Position	1	4%	2%	
Pedal Position	1	4%	2%	
Engine				
Engine RPM (N1)	1	4%	2%	
Engine RPM (N2)	1	4%	2%	
Fuel Flow	1	8%	4%	
Throttle Position	1	4%	2%	
EGT or FTIT	1	16°C	8°C	
All Discretes	1			Any Change Recorded

FIGHTER SIMULATION

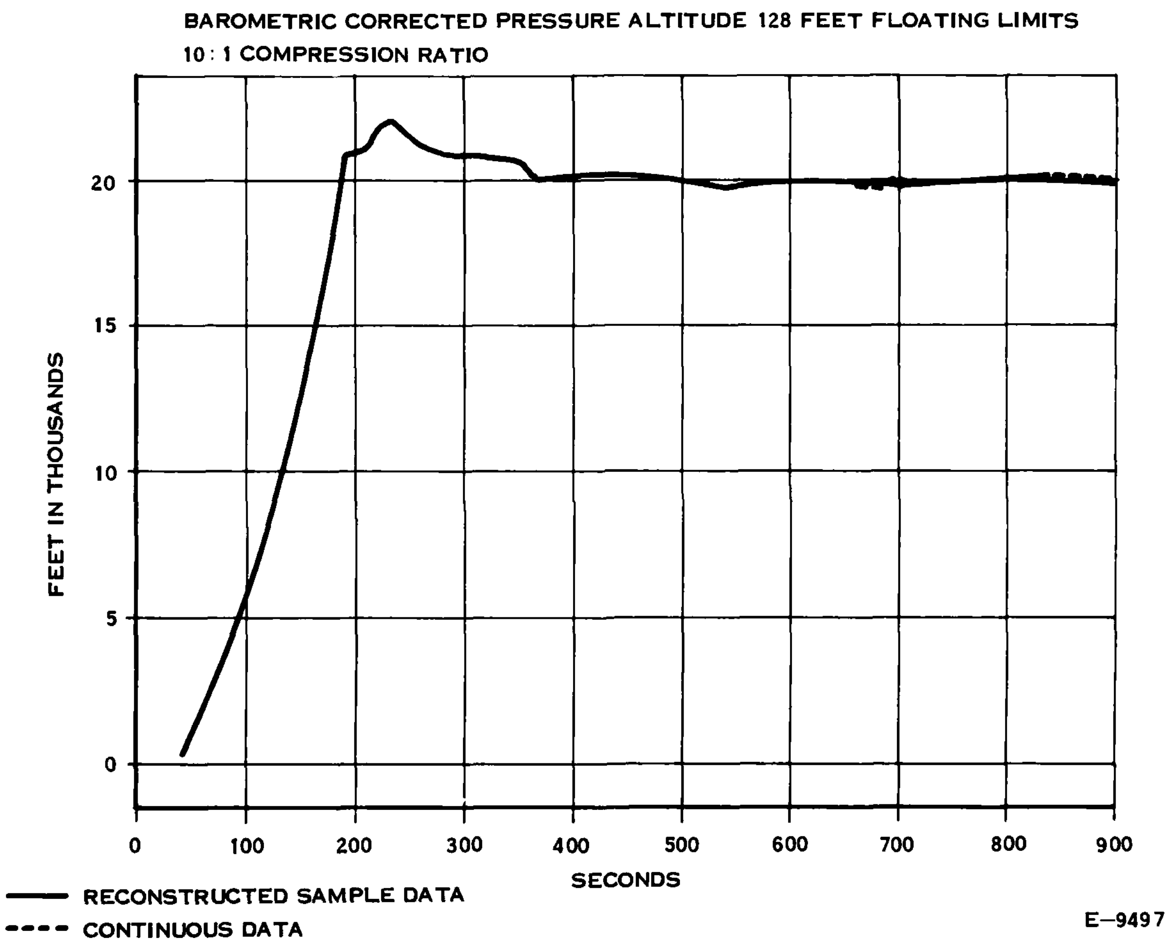


FIGURE 12. BAROMETRIC CORRECTED PRESSURE ALTITUDE PLOT

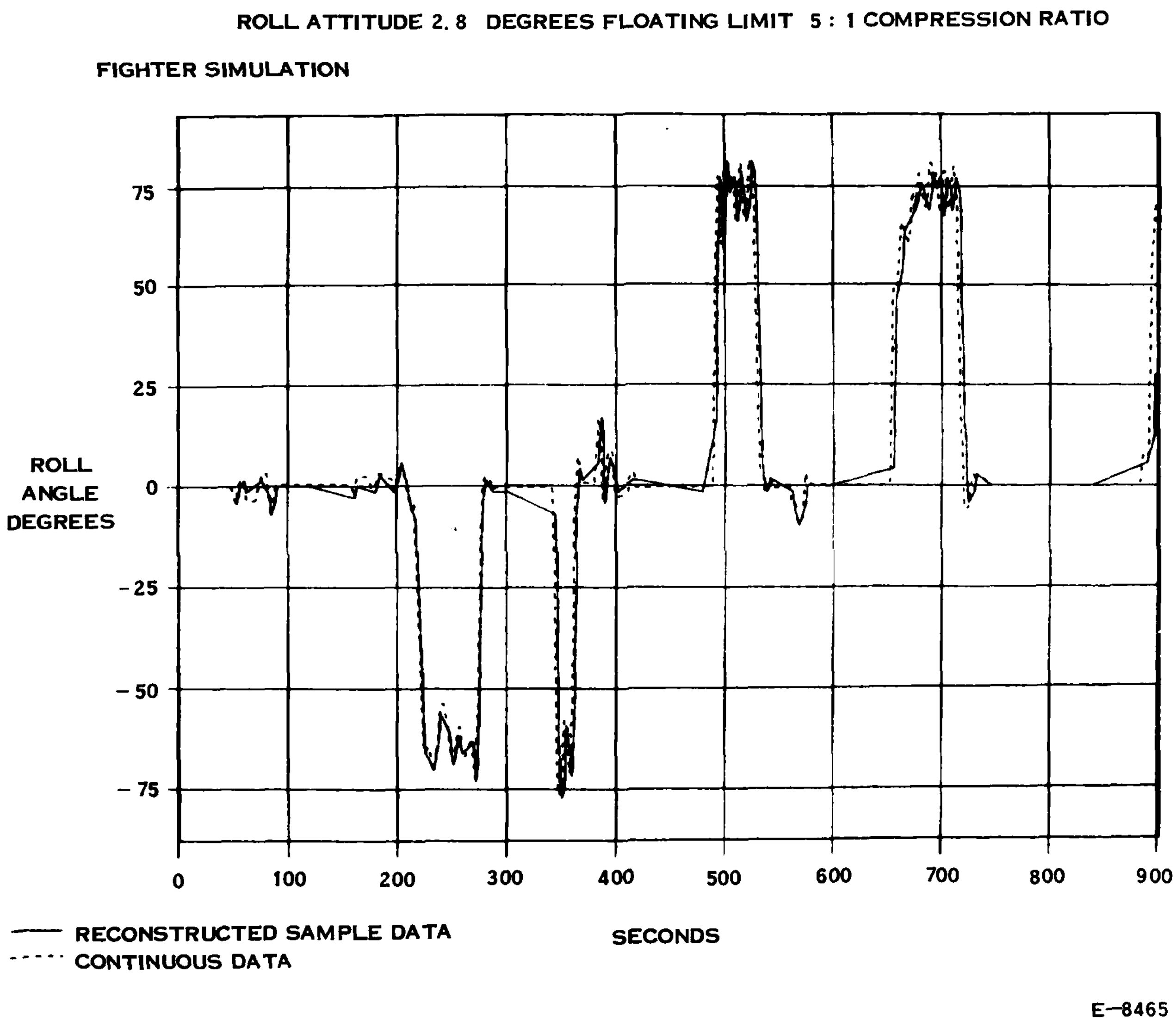


FIGURE 13. ROLL ATTITUDE PLOT

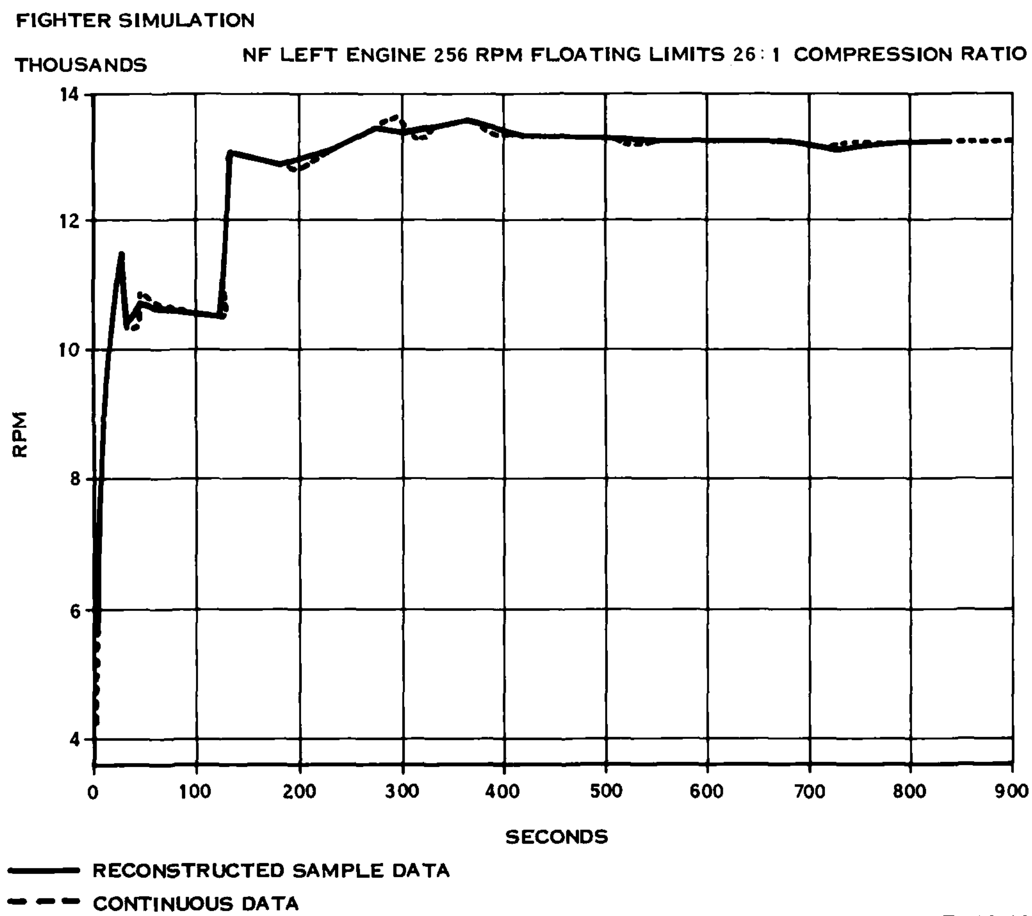


FIGURE 14. N_F LEFT ENGINE RPM PLOT

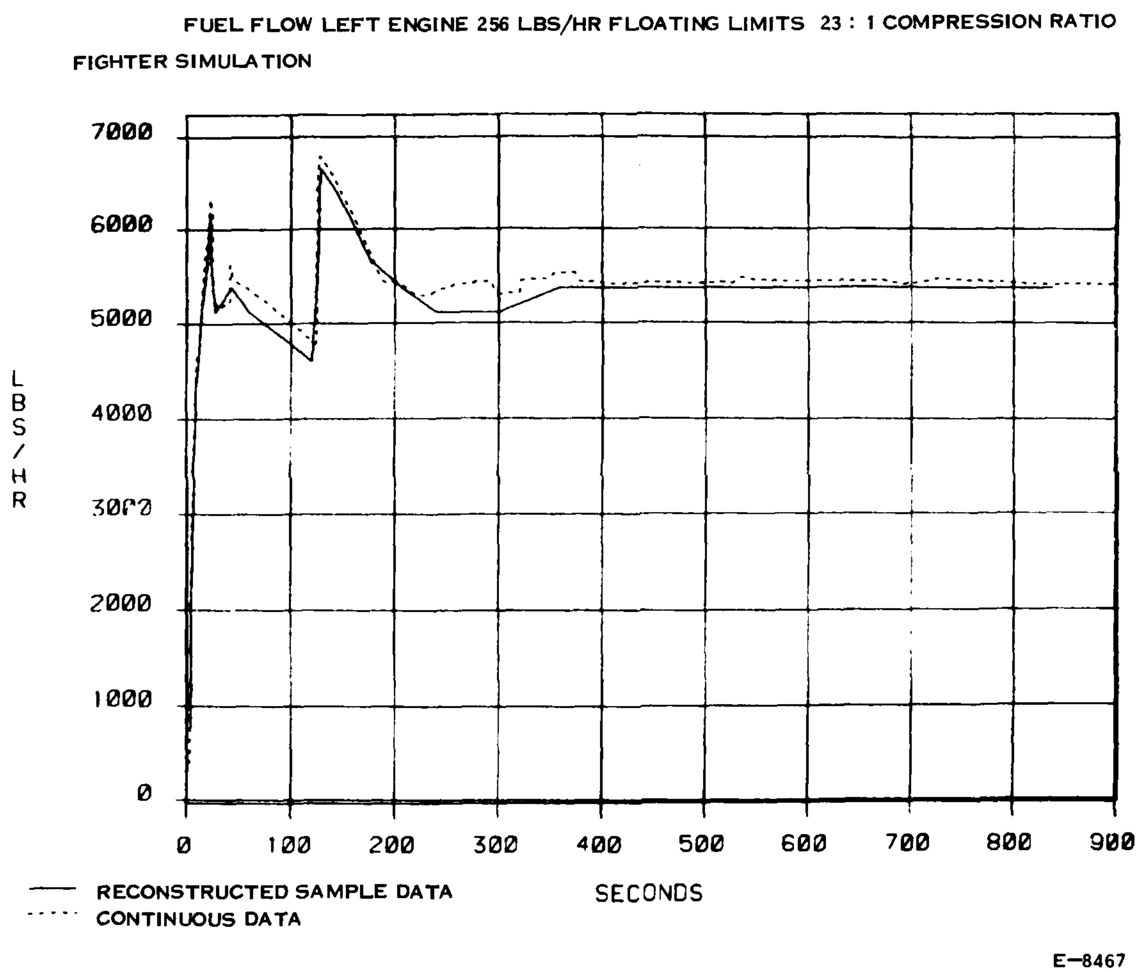


FIGURE 15. FUEL FLOW RATE PLOT

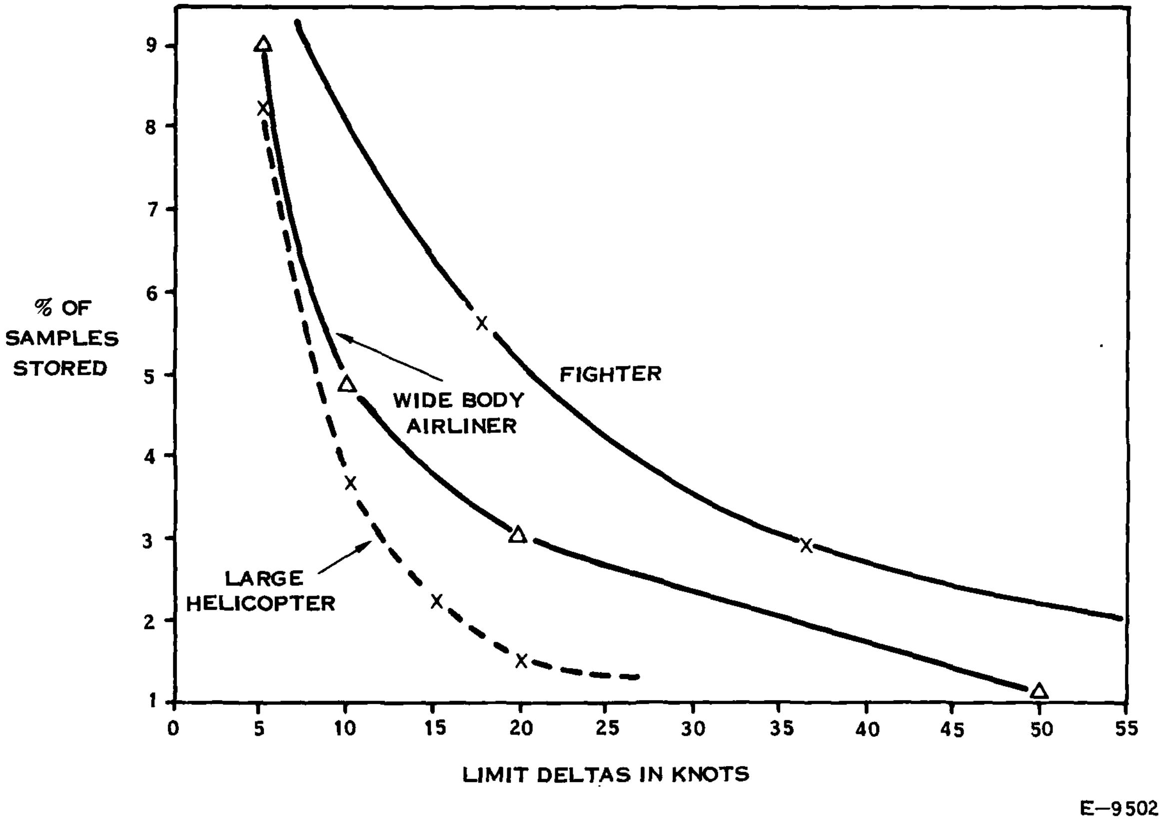


FIGURE 16. EFFECT OF SAMPLE DELTA LIMIT ON COMPRESSION RATIO
FOR VARIOUS AIRCRAFT TYPES

The selected block structure affects the packing efficiency because the frames will be required to fit certain size criteria established in order to fit the selected structure. This results in some padding of the frame to fit the structure.

Either serial or addressable methods can be used efficiently if careful consideration is given to matching the data structure to the selected memory for the crash survivable memory device.

The requirement to record in detail the exact values of a rapidly changing parameter must be determined in cooperation with the responsible mishap investigation agency which analyzes the data. For this study, four (4) samples per second were assumed for acceleration and the parameters used in deriving rate and one sample per second for all other parameters.

If it is determined that a higher rate is necessary, it can be accomplished with little impact on the complexity of the system; however, it can affect the memory requirements.

Variable Frame

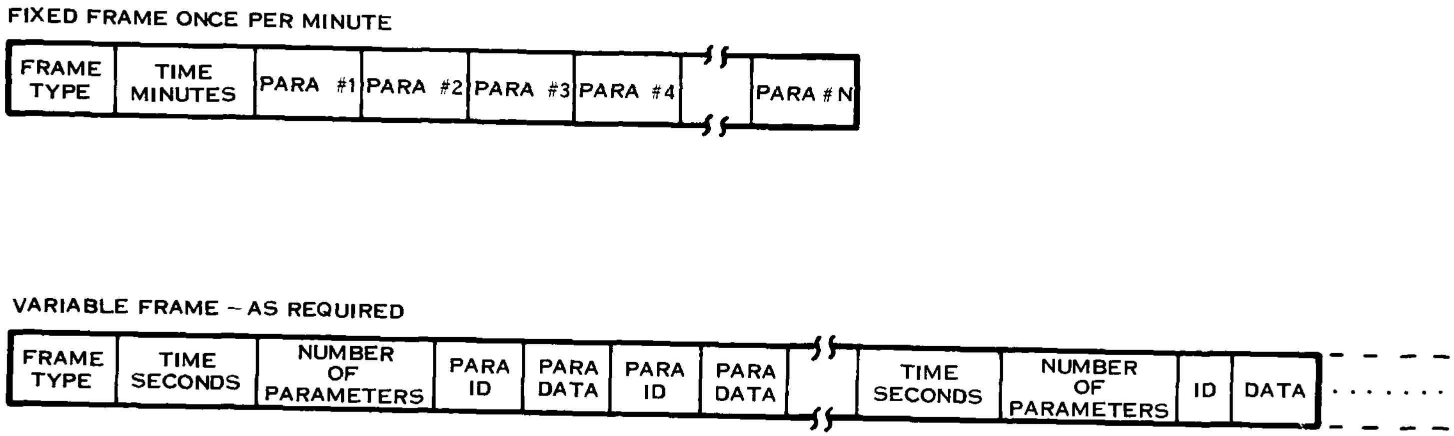
The next step in data reduction is to use a variable frame which only records the parameter that exceeds the limit. Since the frame format is not fixed, it is necessary to add an identifier to each parameter. The time of each parameter must also be identified. It is necessary to construct a format that assembles this data into a string in the most efficient way in order to minimize the overhead. By recording a fixed frame, the minutes are not required in the variable frame.

The variable frame contains a frame type indentifier followed by sample time number of data items to follow followed by the identifiers and data then followed by the sample time etc. Using these guidelines, the format for the variable frame is described in Figure 17. The fixed frame, including time in minutes, is recorded once per minute. If one or more parameters exceed their floating limits in a given sample time; the time, number of parameters following the time, identifiers and data are recorded in a variable frame. As more exceedances occur, the time, number of parameters, identifiers and data are appended to the frame until the time for the next fixed frame occurs.

Other forms of data compression can be postulated. A number of these were studied in the referenced Army AIRS program.

Other forms include Delta modulation and Slope Adaptive Delta modulation.

These techniques are well known in digital transmission of analog information. These techniques would allow data reconstruction with the fidelity essentially limited only to dynamic response where as the above floating limit technique involves static uncertainty affects as well. However, the moderate gains in compression using these more complex techniques above or in combination with floating limits do not appear justified.



E–9467

FIGURE 17 VARIABLE FRAME FORMAT

Actual flight data reconstructed for accident investigator review has been judged satisfactory by these experts using the floating limit approach alone.

2.6 SOFTWARE/FIRMWARE DEVELOPMENT

Hamilton Standard performed tradeoff studies to define the needs for software and firmware necessary to support the flight data recorder system life cycle cost estimate. The goal of these tradeoff studies was to achieve maximum commonality across aircraft type. This goal is accomplished by configuring the input signal conditioning circuitry to accept a variety of signal types. Software selection of variable gains, references and attenuators make this hardware commonality possible. the hardware commonality can be extended to include frequency signals by varying the number of periods counted and to discretes by software selection of thresholds.

Commonality is further enhanced by modular software design. The FDR software functions were grouped according to the degree of commonality that can be expected for various aircraft types. The type of memory technology which is best suited for each group of functions was then identified. Software functions which are least likely to change from one aircraft type to the next are stored in Read Only Memory (ROM) or firmware. Initialization and shutdown routines, interrupt vectoring, built-in test routines, configuration loading from EAROM, limit exceedance routines, processing routines, format routines, and aircraft configuration verification are all examples of this type of software function. Routines which are specific to a particular aircraft should be stored in non-volatile read/write memory such as EAROM. Specific aircraft oriented configuration and tolerance data such as parameter addresses, update rates, limits, and ranges are examples of this type of routine. Random Access Memory is non-volatile read/write memory. This type of memory is well suited for temporary storage of flight programs which are loaded from slower EAROM memory at initialization. This allows multiple aircraft configuration dependent routines to be efficiently stored, modified, or executed with minimum overhead. RAM is also well suited for storage of data as it is being processed by the FDR. Input data, flags and timers, program stack and recent data should all be handled in RAM.

This approach was considered in the life cycle cost estimates which are discussed in detail in Seciton 5.0. Support software for CSFDR playback data, engineering unit conversion, data plotting and simulation programs for algorithm verification was identified to provide cost information relative to supporting flight data recorder use. This support software is discussed in Section 4.0.

2.7 STANDARD CSFDR SYSTEM TRADEOFFS

Three (3) basic type system architectures were concepted for consideration as possible systems for the CSFDR. The first is a distributed system with two or more units using the system data bus and possibly sharing other aircraft system resources. The second is a two unit system with a dedicated communication link between them permitting data collection near the signal source and location of

the Crash Survivable Memory in a more survivable location such as the tail of the aircraft. The third system is a single unit systm with sufficient protection for crash survivability to allow installation at a central aircraft location.

Distributed System (Figure 18)

The distributed system consists of two basic types of units; a data collection and conversion unit(s) and a crash survivable memory unit. The data collection unit collects analog and discrete data which is not available on the data bus. The processing of the data may be done by the data collection unit and transmitted over the data bus to the crash survivable unit or the data collection unit may supply the data to the system for processing by a central computer or a computer in the crash survivable memory unit. The primary advantages of this system is the ability to standardize units for use over a wide range of aircraft where the additional size, weight, and cost would be offset by reduced interconnection weight and cost.

The data collection unit(s) is tailored to the signal processing requirements of a particular aircraft type and is installed as close as possible to the signal sources. The crash survivable unit is common to all aircraft types and can be a common inventory item for a variety of aircraft.

A very large aircraft is required for this system to result in a decreased installed weight. The higher cost, weight and volume, increased complexity, reduced reliability and higher power consumption far out weigh any gains afforded by standardization in the fighter/attack type aircraft. As a future possibility, this becomes viable as a single unit system obtaining all of its input data from other systems on the data bus.

Two Unit System (Figure 19)

The two unit system consists of a signal collection and processing unit and remotely located (preferrably tail location) crash survivable unit. The statistics have shown that the tail area is the part of the aircraft which is most likely to survive a crash and this is the prime reason for the desireability of this configuration. The data collection unit is located in the avionics area to minimize interconnection wiring weight and installation cost. This configuration can also provide a standardized crash survivable memory unit. This configuration has a higher cost (initial and life cycle) than a single unit, is more complex than a single unit and has a higher power, weight, and volume than a single unit. This system is considerably less complex and costly than the distributed system. This system also has the advantage of improved recoverability of the crash protected memory in severe mishaps. Installation considerations in the F15 negate the survivability and recovery advantages of this system on this aircraft. Recovery is eased because of attachment to the aircraft structure which is much more intact than forward areas which are more severely damaged and compacted during a severe mishap.

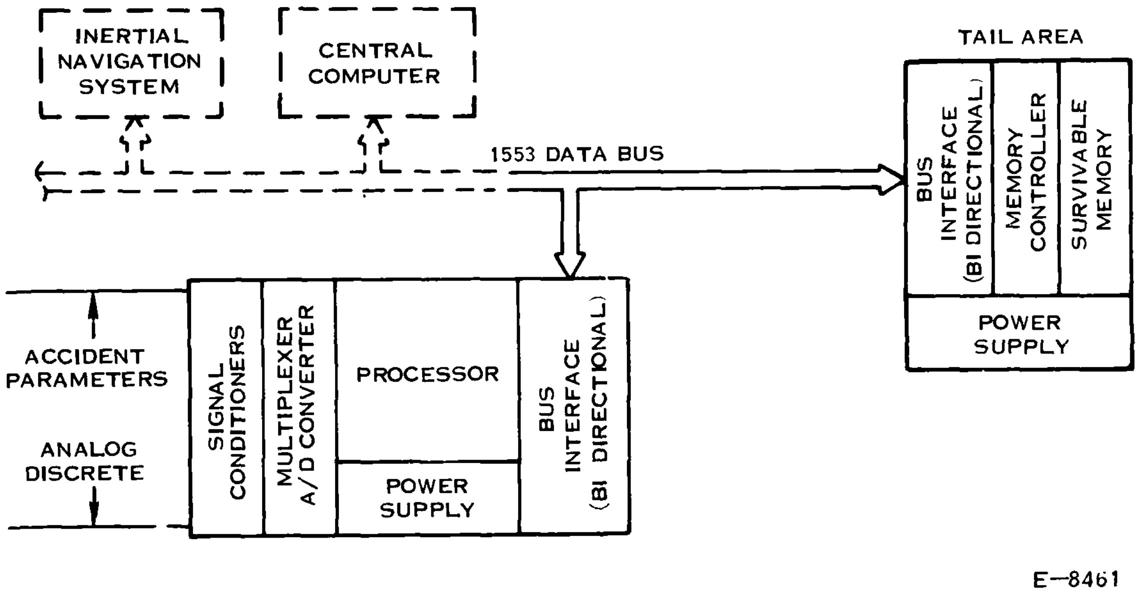


FIGURE 18. CANDIDATE SYSTEM A GENERAL BLOCK DIAGRAM — DISTRIBUTED SYSTEM

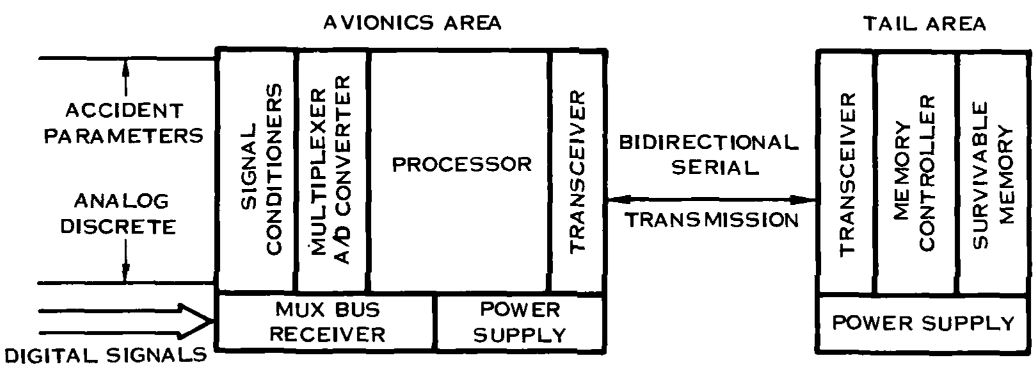


FIGURE 19. GENERAL BLOCK DIAGRAM TWO UNIT SYSTEM

In the tail section of the F15, the thermal environment is marginal to unacceptable in today's electronics and CSMU fire protection technology. The F15 thermal environment in the available tail area location is 160°F continuous with 300°F for 10 minutes and 350°F for 1 minute. Provisions for cooling would cause an unacceptable cost and weight penalty. This environment rules out consideration of bubble memories through the near term for this location.

The cost difference between a single unit and two unit system results from the following items:

* Added hardware for serial communications between two units
* Additional mounting provisions
* Additional access provisions/time
* Reduced reliability due to increased complexity
* Reduced reliability due to severe environment
* Increase for the CSMU logistic support due to additional unit

The added complexity due to the separation of the system into two units results in reduced system reliability resulting in increased maintenance. The increased maintenance time is compounded by the access time at two locations.

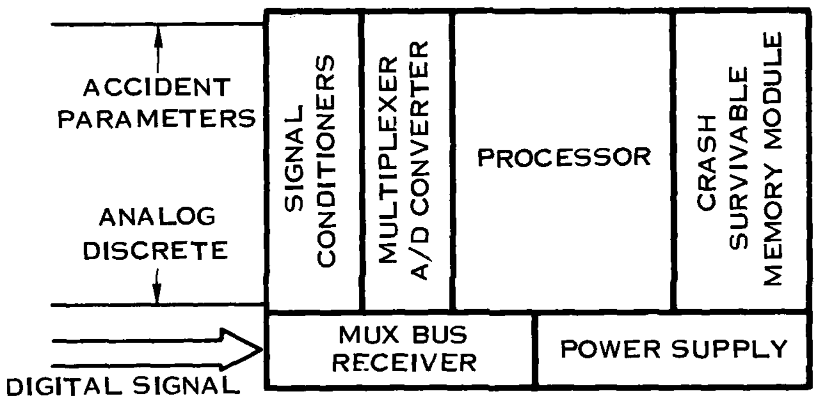
The weight of a two unit system is inherently higher than a single unit system. A higher unit weight is a direct result of the added communication link and added power supply. Additional weight occurs from the additional mounting hardware, brackets and access provisions. There is also a penalty on some aircraft due to the affect on weight and balance due to the center of gravity of the aircraft. Some F16 models (i.e., European supplied) have an aft center of gravity and addition of weight in the tail requires ballast in the nose on a pound for pound basis to offset the weight added to the tail. This does not apply to Air Force inventory aircraft.

<u>Single Unit System</u> (Figure 20)

A single unit system combines the data collection, processing and storage in a single consolidated piece of hardware.

The advantage of a single unit system accrues from the inherent simplification and reduced complexity of consolidated hardware. Additionally, the F15 aircraft has added severe environmental problems associated with a tail area location of a CSMU.

A reduction in survivability is the disadvantage of the single unit system. However, the cost and weight savings on a percentage basis far outweigh the decrease in probability of CSMU surivival.



E–8455

FIGURE 20. GENERAL BLOCK DIAGRAM SINGLE UNIT SYSTEM

Reasonable thermal environment locations are forward where a single unit system would normally be located. Mass memory technology in the form of EAROM is currently available to meet current requirements.

The minimum system complexity combined with the best operating environment results in highest reliability/maintainability.

The minimum installed weight of a single unit system results from the lighter weight of the single unit in conjunction with the requirement to provide mounting for only a single unit.

The single unit system suffers slightly (possible 10% increase compared to a remote CSMU mount in the number of Class A accidents where data is nonrecoverable) relative to the two unit system due to the increased severity of the crash environment in the further forward areas.

For purposes of a worst case CSFDR/CSMU survivability/cost tradeoff only, the following is given:

* All Class B, C & D mishaps are assumed survivable.

* 4 out of 5 Class A mishaps are survivable for a mid aircraft CSMU location.

* 1 out of 5 Class A mishaps are of the "smoking hole" type. It is highly speculative for the mid aircraft location as to what the CSMU degree of survivability would be. However, for purposes of this discussion assume that only one out of two smoking hole mishaps are CSMU survivable. This is very conservative in Hamilton Standard's opinion but will serve in illustrating the point.

* The above indicates that one out of 10 Class A mishaps would have no available CSFDR data for single unit mid aircraft location. Considering Class A mishaps only, the CSFDR would be 10% less effective however, a savings of several times 10%, as compared to a two unit system cost, is realized with the single unit system.

The cost advantage of a single unit system results from a number of items. This configuration is the least complex of those analyzed and therefore requires the least hardware to implement. This results directly in highest reliability and lowest maintenance cost. The use of a single unit also eases the mounting and access problems and requires minimum logistic support compared with a two unit system.

2.8 STANDARD CSFDR DEFINITION

Two standardized CSFDR definitions are considered - Air Force Configuration I and Air Force Configuration II. The Configuration I system handles all the desireable parameters and provides a maximum recording time using available technology. The Configuration II system provides all the essential parameters

with limited recording time using current technology. They will be discussed in reverse order because Configuration I is essentially an expansion of Configuration II.

Configuration II

The recommended CSFDR AF Configuration II concept which follows is based on the folowing Air Force requirements:

a. The configuration shall use currently existing technology.

b. The Air Force Baseline parameter list or suitable alternative signals shall be used.

c. Lowest practical investment operational and maintenance costs is required.

The following additional factors are to be identified.

a. Include additional desireable parameters where there is a minimum impact on the system.

b. Add coverage for any parameters which are of value in a high percentage of accidents.

c. Installed weight, balance and volume are significant considerations.

d. Installation shall consider survivability factors.

e. Physical, mechanical and thermal environment impact shall be considered.

f. Production costs and logistic support costs shall be held to a minimum.

A single unit system configuration has been selected based on the above considerations.

The system is configured with a current technology 8085 microprocessor or equivalent and MNOS electrically alterable read only memory for the crash survivable data storage. This is proven technology which is capable of meeting the system requirements. Table 51 provides an estimate of the crash survivable memory requirements. In addition, LSI gate array and leadless chip carrier packaging are current technology approaches to improved package density and weight savings which are considered in the size, weight and cost estimates for the CSFDR.

A detailed block diagram of the Configuration II CSFDR is shown in Figure 21 with a summary of required signal types per aircraft summarized in Table 41. The CSFDR unit is configured to be compatible with all three aircraft - A10, F15 and F16. The unit includes extensive self test capability to indicate to maintenance personnel that the unit requires service.

TABLE 51. CSMU MEMORY REQUIREMENT ESTIMATES

ESTIMATE BASED ON A10 DATA:

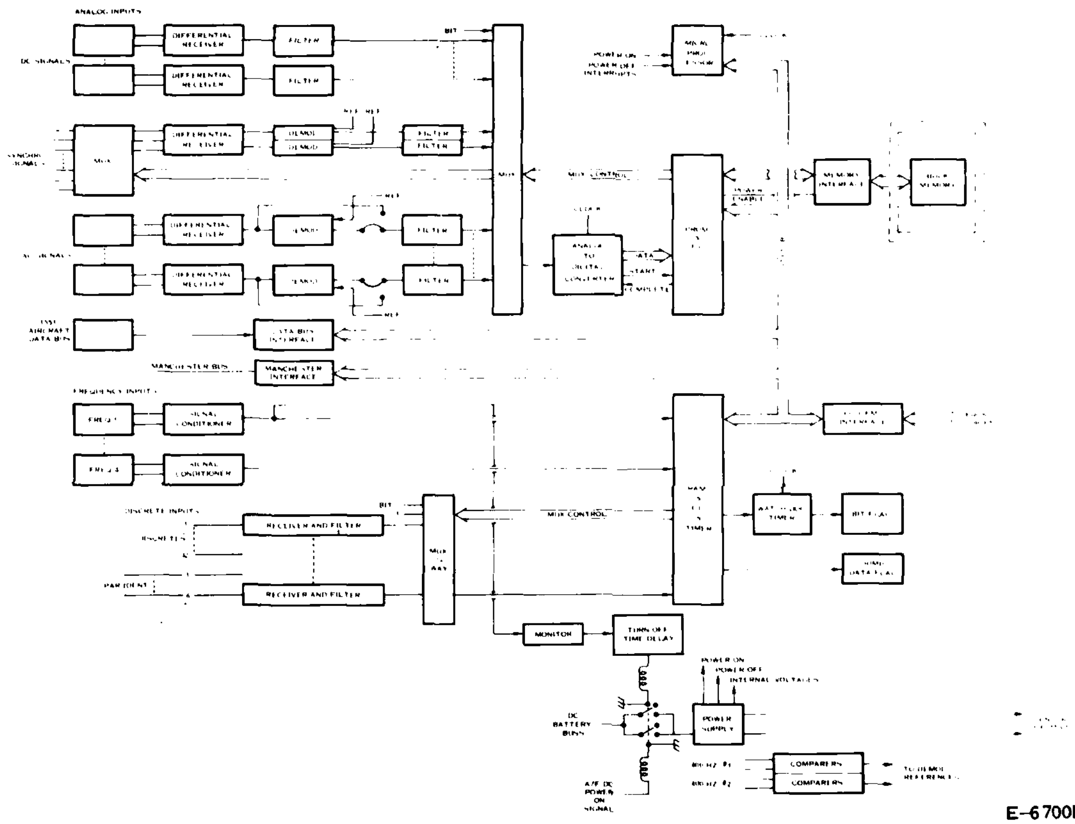
24 ANALOG PARAMETERS @ 1/SEC	24		
6 PARAMETERS @ 4/SEC	<u>24</u>		
ANALOG PARAMETER/SEC	48		
TYPICAL PARAMETER 8 BITS			
TYPICAL RECORDING TIME 15 MINUTES			
UNCOMPRESSED ANALOG DATA TOTAL BITS (48 X 8 X 60 X 15)		= 345,600 BITS	UNCOMPRESSED ANALOG
TYPICAL COMPRESSION FACTOR = 7 (345,600/7)		49,371 BITS	COMPRESSED ANALOG
DISCRETES 45 BITS / MIN X 15 MIN = 675 BITS		50,046 BITS	TOTAL
ASSUME + 1.5 TIMES FOR HIGH ACTIVITY		= 125,115	HIGH ACTIVITY TOTAL

ESTIMATE BASED ON FIGHTER SIMULATION

ASSUME FIGHTER PARAMETERS TYPICAL	
15 MINUTE SEGMENT AVERAGE	36,638 BITS
ASSUMING 1.5 TIMES FOR HIGH ACTIVITY	54,957 BITS
ADD 50% FOR UNSIMULATED SENSOR NOISE AND RELATED EFFECTS	45,797 BITS

MEMORY REQUIRED SIZE FOR 15 MINUTES MINIMUM DATA <u>131 K BITS</u>

E-8485



E-6700B

FIGURE 21. DETAILED CSFDR BLOCK DIAGRAM CONFIGURATION II

The ability to flag specific predefined conditions which should cause an examination of the stored data can also be supplied.

On aircraft readout of the survivable data is provided by a Ground Readout Unit (GRU) or a Field Maintenance Unit (FMU) which can also display input data and/or stimulate the system input signals for system checkout and fault isolation on the aircraft.

Data from mishaps can be read out by removal of the unit from the aircraft if it is intact and operational. Otherwise, the unit or survivable module remains are removed and returned to the depot or manufacturer for readout.

Configuration I

The AF Configuration I system requirements are the same as Configuration II except for handling a maximum number of flight parameters, extended recording time, best available technology and meet the physical size and construction constraints of a fighter aircraft. A block diagram is shown in Figure 22.

The expanded signal complement adds the secondary parameter signal complement to the baseline parameters. The added signal requirements are summarized in Table 42. The extended recording time will be gained by expanding memory capacity. It is expected that memory capacity can be economically expanded to 1 million bits in the 1985 time frame by use of bubble memory with LSI interface chips which will operate over on expanded temperature range.

High density packaging will use advanced microprocessor and LSI chips, gate arrays and leadless chip carriers and chip components to provide minimum size and weight.

Mechanical Design

General

The CSFDR mechanical design concept is comprised of two (2) main subsystems, the Electronics Unit containing aircraft interface circuitry, signal conditioners, multiplex circuits, analog-to-digital conversion circuits, the microprocessor control and resident program.

The second subsystem consists of the Crash Survivable Memory Unit (CSMU) which houses the solid-state, nonvolatile memory device.

The design concept for the CSFDR Electronics Unit is shown in Figure 23. The Electronic Unit will be designed to meet the environmental requirements for Class II airborne equipment per MIL-E-5400R.

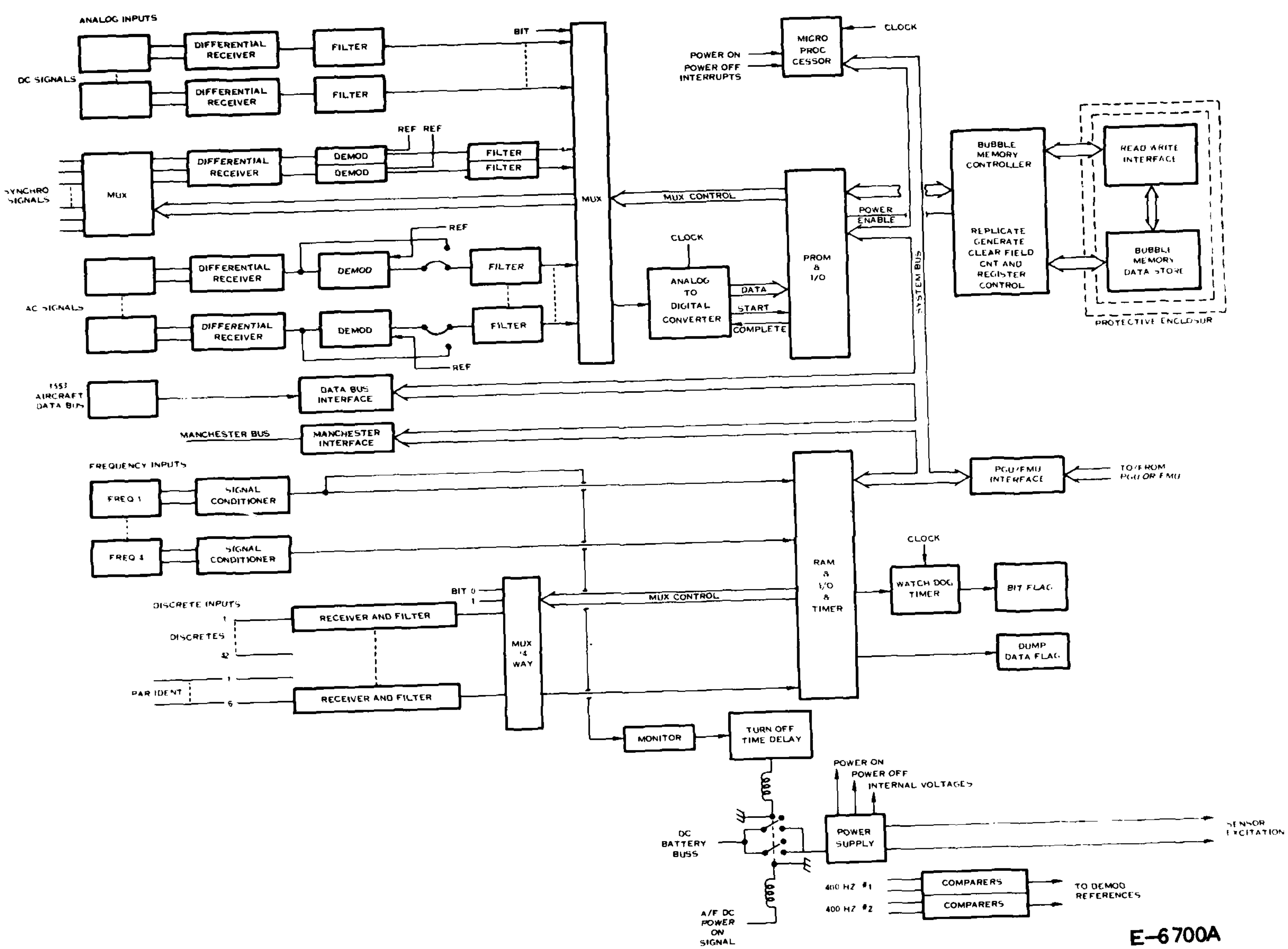
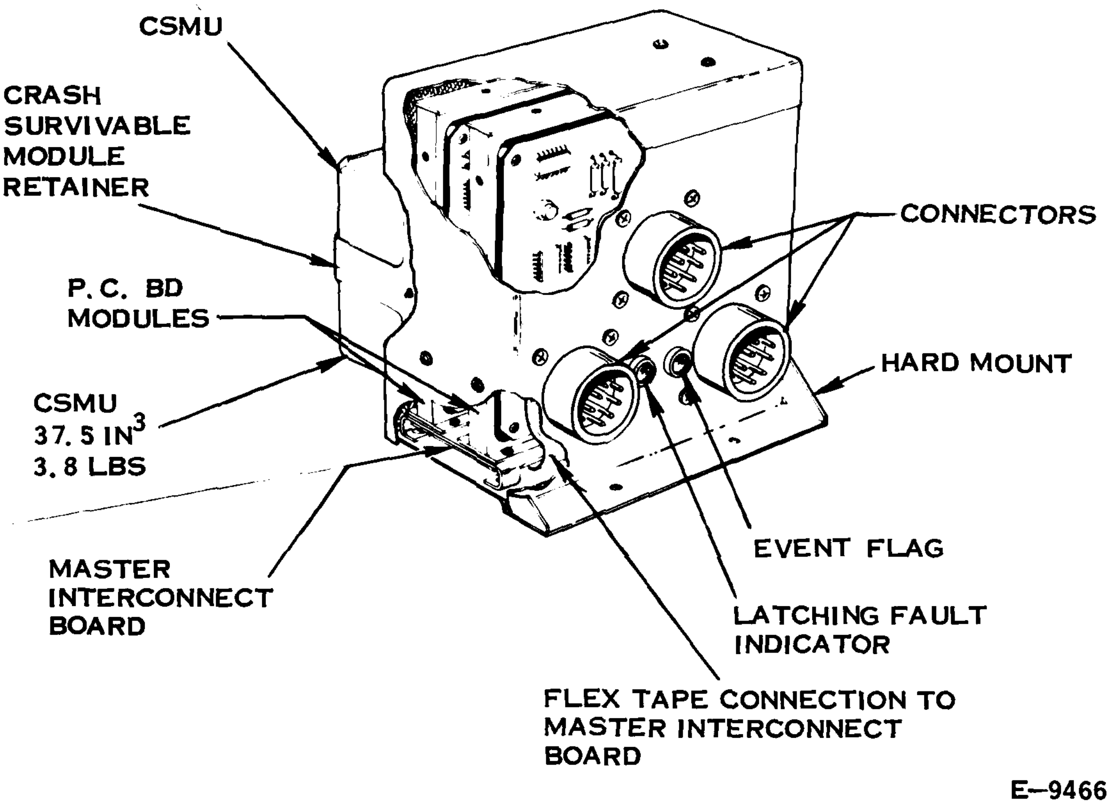


FIGURE 22. DETAILED CSFDR BLOCK DIAGRAM CONFIGURATION I



ESTIMATED PRODUCTION CHARACTERISTICS
• WT 9.5 LBS (MAX. EXCL. FLANGES)
• SIZE 6.7 LONG
6.5 HIGH
6.8 WIDE
• VOLUME 177 IN^3
• MATURE RELIABILITY – 8,300 HOURS MTBF
• POWER CONSUMPTION – 25 WATTS MAX (15 WATTS AV.) – AT 28 VDC

FIGURE 23. CSFDR PACKAGE – 1982 APPLICATION

The system is estimated to be less than 6 inches cubed and weighing less than 9.5 pounds including the CSMU. The electronics unit would contain four (4) printed circuit (PC) boards partitioned as follows:

1. Power Supply

2. Analog Signal Conditioner

3. Processor and Frequency Interface

4. Memory Module Control

Each board will measure approximately 5.75 inches X 5.25 inches and contain eight (8) layers. The four PC boards will be interconnected via a multi-layer master interconnect board which will also connect to the CSFDR input/output (I/O) connectors and CSMU module via flex tapes. I/O connectors will contain sufficient connections for system test and/or data retrieval via a Ground Readout Unit (GRU).

An EVENT and BIT latching indicator will be provided for maintenance crew visual inspection to determine system operational status. The EVENT indicator will alert the ground crew that data representing an aircraft unusual incident or response was saved for ground evaluation. Readout of the CSFDR memory would then be accomplished with the GRU in order to evaluate the incident. The BIT indicator alerts the ground crew that the CSFDR was shutdown due to a malfunction and thus requires ground checkout. The BIT indication may indicate either a malfunction of the CSFDR or related sensor malfunction.

The CSFDR Electronics Unit housing will be hard-mounted on board the aircraft and will contain open ventilation for convection cooling of the electronics.

The CSMU will be strap mounted to the Electronics Unit utilizing a burn away harness which will allow the CSMU to fall away from the electronics during a fire. This design feature is necessary to allow unrestricted intumescing of the CSMM outer insulating shell during a crash fire.

Crash Survivable Memory Unit (CSMU)

The heart of the CSFDR is the armored module used to protect the solid state memory device during and after an aircraft incident involving high impact shocks and piercing loads resulting from aircraft breakup, crushing loads resulting from aircraft wreckage landing on the armored module, flames resulting from ignition of aircraft fuel and possible submergence in sea water. To accomplish the necessary protection of the memory device, the armored module (Crash Survivable Memory Unit - CSMU) incorporates four (4) discrete water filled insulating layers and a hermetic housing for the memory device. This concepted design configuration is similar to a design which has demonstrated compliance to and exceeded the requirements of TSO-C51a.

Intumescent Shell

The intumescent shell is bonded to the armored housing and forms the exterior of the CSMU. The shell is made up of layers of vulcanized synthetic rubber containing an intumescent ceramic material and includes a wire mesh reinforcement between the outermost and middle layer of rubber. The shell consists of a flat cover and a molded rectangular box. The overall thickness on any side is 0.25 inches. In the assembled state, the wire mesh in the cover and in the rectangular box are bonded together to provide continuous reinforcement around the CSMU periphery.

The intumescent shell provides the initial thermal barrier to 1100°C flame resulting from an aircraft aviation fuel fire. The insulating shell begins to intumesce at approximately 500°C. As the flame temperature increases to 1100°C, the material forms a tough insulating char which provides a high thermal resistance to protect the memory module from the high external ambient temperature via the process of high surface radiation, absorption of energy through chemical process of decomposition and removal of energy through the process of transpiration.

Armored Housing

The armored housing consists of a flat cover and a rectangular box. The cover is bolted to the housing with cap screws. Both pieces are made from 7075-T6 aluminum alloy. This material has excellent resistance to penetrating loads plus low weight considerations.

Hermetic Sealed Memory Module

The memory device is enclosed in a hermetically sealed metal package. Internally, the memory is mounted on printed circuit boards. I/O signal leads are routed out of the hermetic package via a tubular metal passageway. The hermetically sealed package is enclosed in the water boiler layers inside the armored module. Potting is applied around the memory device inside the hermetic package with air pockets in the potting providing protection against forces caused by freezing of the water internal to the armored module.

Aircraft Installation

The CSFDR aircraft installation results from considerations of survivability, effective operation, cost and weight. Installation requirements were reviewed with the airframe manufacturer to develop estimates of man-hours required for installation as either a retrofit kit or during aircraft manufacture.

The locations recommended for the CSFDR unit are covered in Section 2.2

The A10 CSFDR installation would include the following items:

* CSFDR Electronics Unit

* Aileron Position potentiometric sensor assembly

* Rudder Position potentiometric sensor assembly

* Elevator Position potentiometric sensor assembly

* Power Lever Angle sensor assembly

* Airframe wiring, clamps, conduits, connectors and circuit breaker

All other aircraft parameters are available as electrical signals and do not require special sensors.

The position sensor assemblies would be similar to assemblies currently used to measure positions as a part of other aircraft systems such as the flight control system.

Installation Weight

The weight of the installation over and above the CSFDR unit was estimated to be approximately 9.0 pounds. Table 52 summarizes the installation weight data.

CSFDR Installation Effort

As a typical example of the effort requred to install AIRS, the installatioin guidelines were given to the participating airframe manufacturer and a preliminary estimate was prepared. The estimate considered installation as a retrofit kit.

The recurring man-hour estimate to install the CSFDR and added sensors considered wire runs, numbers of wires, clamping, armoring, unit and sensor installations, bracketry, threaded floor receivers, connectors, etc.

In addition, the estimate considered standard learning curve factors and estimates for typical lot buys of systems and installation.

TABLE 52. INSTALLATION WEIGHT SUMMARIES

	A10	F15	F16
• UNIT	9.5	9.5	9.5
• SUPPORTS AND CLAMPS	1.0	0.5	0.5
• WIRING	7.0	3.0	3.0
• MISCELLANEOUS	--	1.3	--
• BASELINE SENSORS @ 0.3 PDS EA.	1.0 1.0 (4)	.0 1.0 (4)	
TOTAL	18.5	15.3	13.0

3.0 SYSTEM EXPANSION

Using the standard CSFDR defined in Section 2.0, several areas of system expansion are considered herein. Tri-service application along with possible utilization of a common system for large multi-engine aircraft are studied. Future aircraft are also addressed in terms of affects on CSFDR configuration. Finally, expansion of the basic CSFDR is examined in maintenance monitoring areas such as engine and airframe health and flight control fault status. From these analyses, an integrated concept is outlined.

3.1 TRI-SERVICE STANDARDIZATION

For the purpose of the tri-services standardization, typical current generation aircraft were categorized in Table 53. This classification is only intended to classify general types for consideration of criteria which influences standardization and the respective service requirements.

Patrol, Transport, Tanker, Bomber Aircraft

This type of aircraft carries a large fuel load and has a large mass. The large quantity of fuel can support long duration fires with long wreckage cool down times which places very severe fire protection requirements on a centrally located CSMU. This type of aircraft; however, has an acceptable tail temperature environment for mounting a remote memory module and associated electronics. The tail area is also suitable for mounting a deployable memory. This is desirable because flight missions for this type aircraft are frequently over water. Aircraft whose mission is primarily over deep water, where recovery of the aircraft is difficult or impossible, require a deployable survivable data module which is ejected from the aircraft prior to or during a crash impact. The U.S. Navy and U.S. Coast Guard conduct flight missions primarily over water. The U.S. Marine Corps and the Air Force Transports and Bombers have a combination of over land and over water missions.

The data acquisition function should be centrally located close to the majority of the signals either in the cockpit or electronics bay area. This area is a recommended area for survivability for the above reasons.

This type of aircraft therefore lends itself to a two unit system where data acquisition and survivable memory are physically separated or where additional fire protection is required.

An additional factor in these large aircraft is the requirement for a voice recorder function in addition to the Flight Data Recorder. There is more coordination required between crew members that entails considerable voice communication which may provide mishap investigation information.

TABLE 53. TRI-SERVICE AIRCRAFT MATRIX TYPICAL CURRENT GENERATION TYPES

		FIXED WING		
BRANCH	ROTARY WING	TACTICAL & SUPPORT	PATROL, TRANSPORT	BOMBER
AIR FORCE	CH53 HMX	F15 F16 A10	C130 C141 C5A	B52 B1*
ARMY	UH60A CH47D AH64	OV–1/RV–1	––	––
NAVY & MARINES	CH53 LAMPS	A7 F14 AV 8 F18*	P3 S3 E2/C2	

E–9198

*MORE TYPICAL OF NEXT GENERATION DATA BUS AIRCRAFT

NOTE: THE LIST IS NOT COMPLETE BUT IS GIVEN TO INDICATE AIRCRAFT CONSIDERED TYPICAL OF VARIOUS CURRENT GENERATION TYPES WHICH WILL BE IN INVENTORY IN THE FORESEEABLE FUTURE.

Rotary Wing, Fighter and Tactical Aircraft

Size, weight and cost minimization are more critical on these aircraft than on the larger aircraft. Aircraft space and location constraints and weight and balance affects on these aircraft can be particularly severe especially when aircraft space is a premium and weight and balance limitations may already be a problem. Additionally, the severe tail thermal environment in some supersonic aircraft strongly favors a mid fuselage location for the CSFDR. The smaller fuel load and lower mass of these aircraft limit the fire duration and the wreckage cool down time. Voice recording is of limited utility in most aircraft of this type which are crew limited.

General Requirements Summary

The general requirements of the tri-service aircraft are summarized in a tri-service recording systems block diagram in Figure 24. The U.S. Navy over water patrol type aircraft require a deployable system which includes voice. The U.S. Air Force bombers and transports may use a deployable system or a non-deployable system which should include voice recording. The U.S. Navy and U.S. Marine Fighter attack helicopter and trainer aircraft can be spread across all three (3) configurations. The Air Force and Army fighter, attack, trainer, helicopter observation and surveillance aircraft lend themselves to non-deployable flight data only systems. Standardization of the CSFDR Configuration I or Configuration II could be achieved for the aircraft data only non-deployable system.

3.2 FUTURE AIRCRAFT APPLICATION

The trend in aircraft system avionic architecture is toward a general purpose data bus structure. New aircraft being designed and concepted are making extensive use of the data bus while older aircraft systems are being retrofitted with data bus systems. It is therefore assumed that future aircraft will be equipped with a digital data bus. The aircraft instrumentation is becoming increasingly digital which leads to the conclusion that, in the future the signals required as inputs to the FDR will be available on the digital data bus with a few possible exceptions which will likely be discretes.

A single unit FDR will continue to be the most viable approach; however, it will be a data bus oriented unit as shown in Figure 25. Since it will receive its inputs from the data bus, additional flexibility in installation will be available to the airframe manufacturer. Location of the CSFDR for improved survivability will more readily be achieved since the FDR can be easily accommodated in more remote aircraft locations. This will allow the FDR to be located in the most survivable, environmentally suitable location available.

The future CSFDR will handle all data, except for a few discrete inputs, from a bi-directional data bus. Processors and data bus interface LSI microcircuits will be able to handle the processing and data bus interface requirements with a minimum of hardware size, weight and cost impact. Large capacity

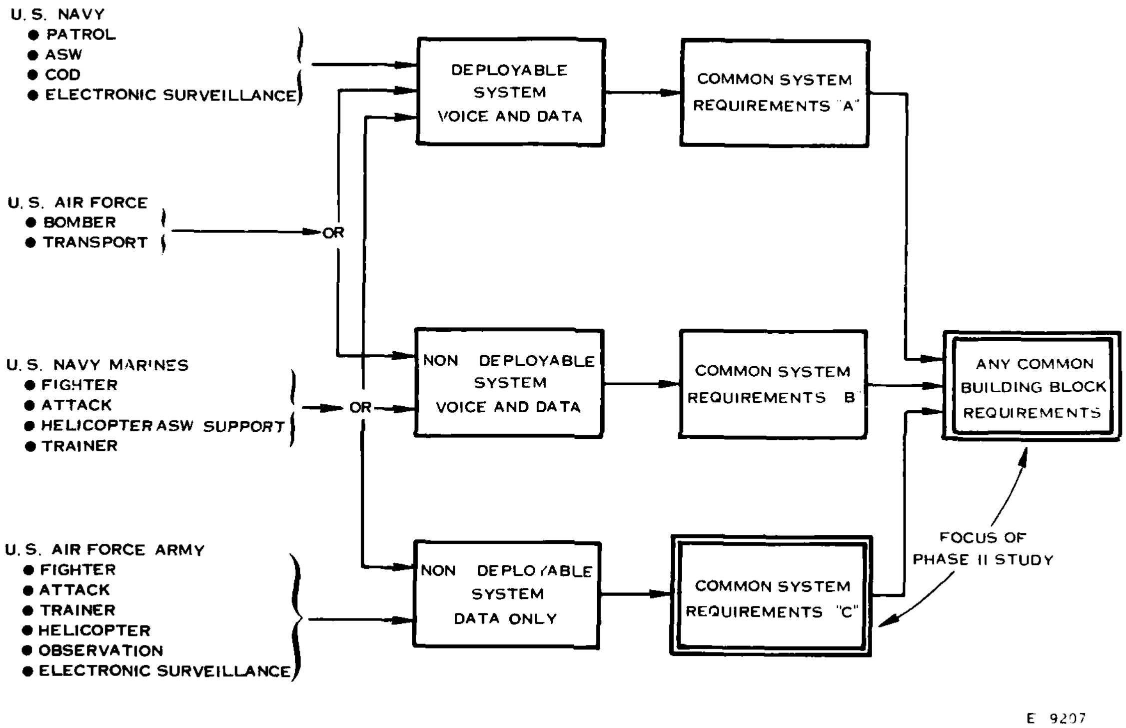


FIGURE 24. TRI–SERVICE FLIGHT RECORDING SYSTEMS BLOCK DIAGRAM

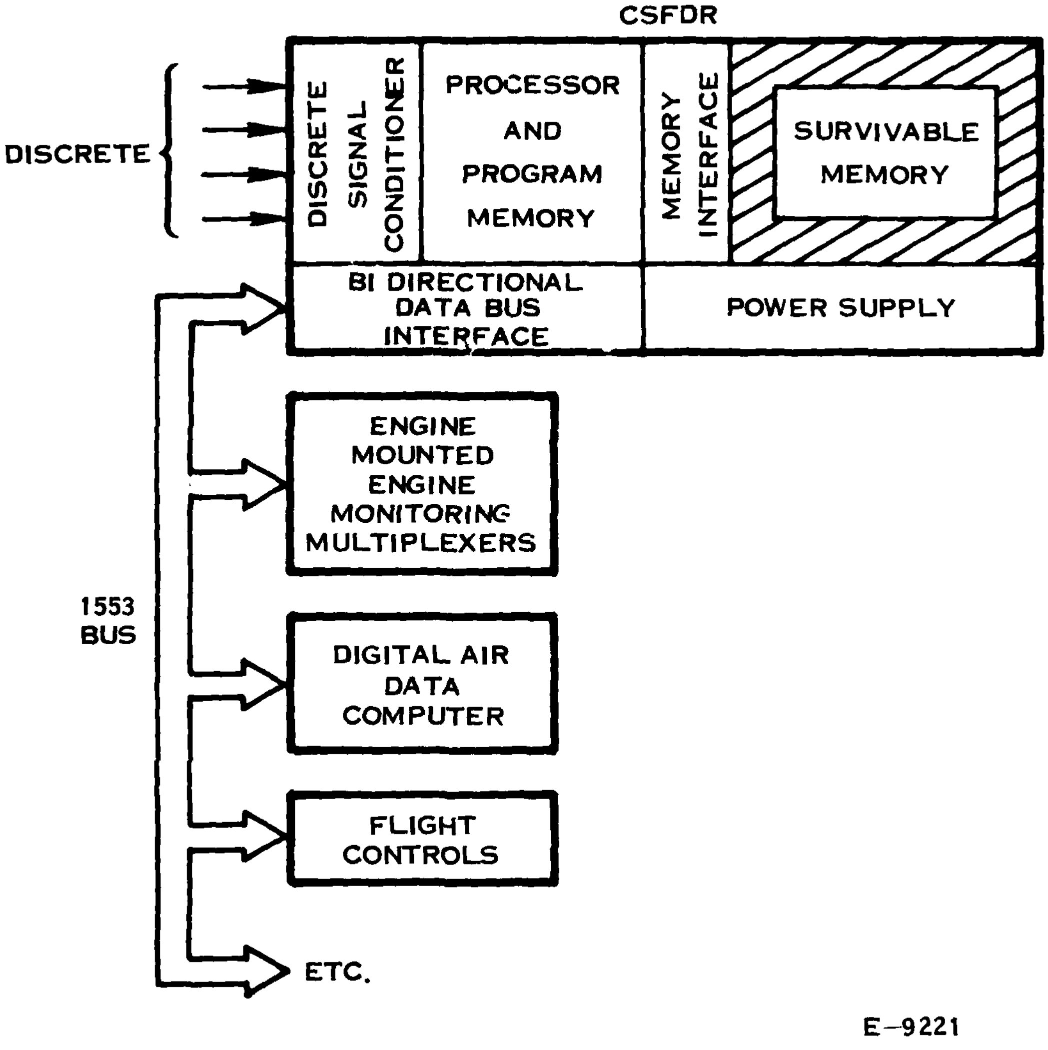


FIGURE 25. CSFDR BLOCK DIAGRAM FOR FUTURE AIRCRAFT

memories will become available in extended temperature range suitable for the CSFDR requirement making one (1) million bit storage practical in both bubble and integrated circuit memories. The signal capabilities of the Configuration I CSFDR should be practical in reduced size and weight since no analog signal interfacing will be required.

3.3 APPLICATION TO AIR FORCE TRANSPORTS AND BOMBERS

Air Force Transports and Bombers have additional requirements over the CSFDR requirements discussed in Section 2.0 of this report. The additional requirements are in the need for recording voice information and in more stringent survivability requirements. A block diagram of a Flight Data Recorder concept which includes voice recording capability is shown in Figure 26.

The added crew communication and the ability of the aircraft to absorb the higher weight and size of an FDR with voice recording capability make voice recording desirable in this category of aircraft. Voice recording will require a significant increase in signal processing capabilities. Voice recording requires orders of magnitude more data storage than aircraft parametric data over a comparable time period. The minimum sample rate for voice recording will be 10,000 samples per second for a Pulse Code Modulation System. In order to achieve the data compression necessary for solid state recording, a powerful processor and sophisticated processing algorithms are required. The added processing and data storage would more than double the size of the CSFDR.

The high fuel capacity and large wreckage mass provide the potential for extended exposure to fire and an extended post fire cool down period. This means the CSFDR must be designed for extended fire exposure or must be located away from the fuel and mass concentrations in the tail area. An alternative solution is to make the CSMU deploy from the aircraft. The more viable options are tail mounting and/or deployment of the crash survivable memory unit. A two unit concept is therefore favored for the CSFDR - a data collection unit centrally located and a tail mounted unit for the Crash Survivable Memory which may be either deployable or non-deployable as deemed best by the Air Force.

There is no unit commonality with the Configuration I or Configuration II CSFDR due to the greatly expanded requirements and inherent system differences. Some internal module commonality is acnievable; however, this commonality has little significance for life cycle cost considerations.

3.4 LARGE SCALE SYSTEM STANDARDIZATION

The possibility of standardizing FDR's from the system level down to modular building blocks has been evaluated. The Configuration I and Configuration II CSFDR on a system level (Line Replaceable Unit) is feasible in selected areas of small fixed wing and helicopter category aircraft. Standardization of a single unit CSFDR Configuration I or II capable of handling the CSFDR requirements of current Army fixed and rotary wing and the A10, F15 and F16 is feasible.

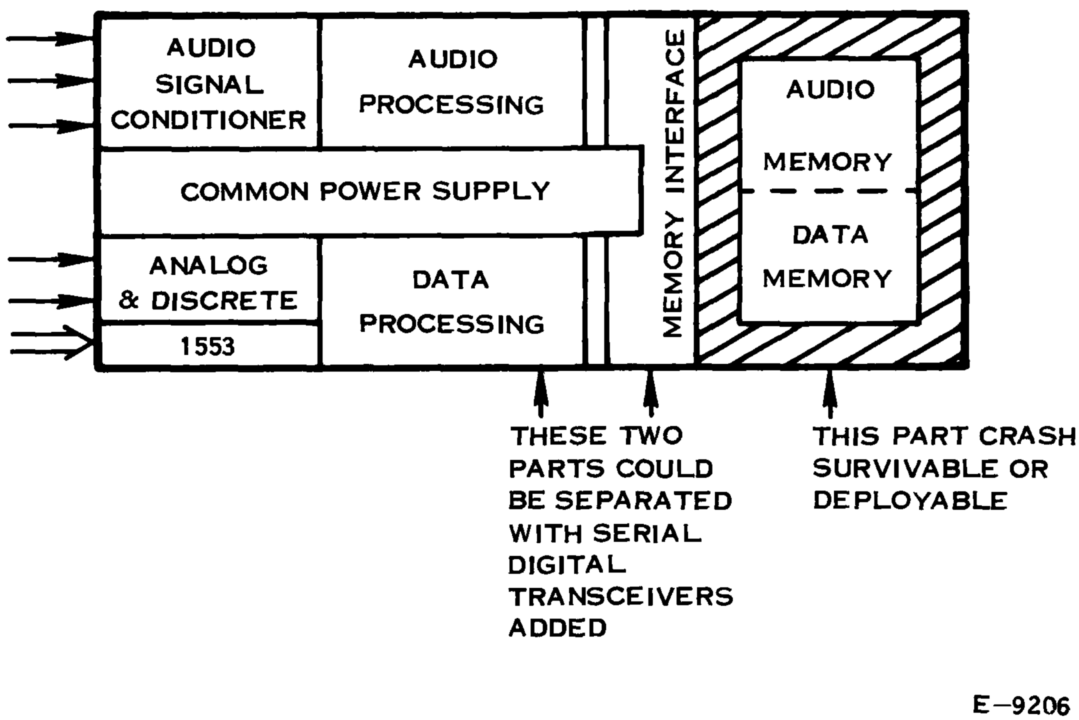


FIGURE 26. AIR FORCE TRANSPORT AND BOMBER FLIGHT DATA AND VOICE RECORDER

For the purposes of standardization studies, aircraft were categorized into three groups.

A. Rotary wing and small fixed wing

B. Bombers, Transport and Patrol aircraft

C. Fighter attack and trainer aircraft

The signal conditioning requirements for the above category aircraft are summarized in Table 54 for typical aircraft with known requirements. Individual aircraft parameter lists are listed in Tables 55 through 65.

Using an 8085 microprocessor or equivalent operating with a 6 MHz clock, the relative processing time required to perform the FDR function for each of these aircraft categories was estimated. Class A aircraft utilize 30% of available processor time. This estimate was based on actual Black Hawk helicopter flight test results. Class B and C both utilize 40% of available processor time even though Class B aircraft processes a larger number of parameters. These estimates include only the recording of parametric data. The impact of voice recording is discussed later.

The data storage requirements for all three (3) classes of aircraft are such that standardization is feasible if only data recording is considered. The data storage requirement for Class A aircraft was determined in the referenced study [1] to be thirty-two (32) kilobits. The data storage requirements for Class B aircraft were derived from the requirements for a large commercial jet transport. This requirement was determined to be ten (10) Megabits without data compression to record the FAA mandatory parameters at required sampling rates for twenty-five (25) hours. This requirement doubles when the Air Force selected parameters are considered. An average sampling rate increase of 50% due to the different flight profile for this type of aircraft increases the storage requirement to thirty (30) megabits. If the required recording time is decreased to fifteen (15) minutes from twenty-five (25) hours, the storage requirement becomes three hundred (300) kilobits. This requirement is reduced to thirty (30) kilobits when data compression techniques are utilized to achieve a ten to one data compression. When Navy requirements for this class of aircraft are included, the recording time increases from fifteen (15) to thirty (30) minutes. The data storage requirement to cover all aircraft in this group is therefore sixty (60) kilobits. Sixty four (64) kilobits is the nearest binary multiple. However, since a combined voice and data system appears to be desireable for this aircraft class, the mass memory requirement, including digitized audio storage, is in the five (5) to ten (10) megabit range. The actual number depends upon a number of factors such as recording time, voice compression techniques and the number of voice channels to be recorded.

TABLE 54. AIRCRAFT GROUPS BASIC REQUIREMENTS FOR SIGNAL CONDITIONING

SIGNAL TYPES	AIRCRAFT TYPES		
	A	B	C
DIGITAL DUAL 1553 SPECIAL (F15)	--	--	 1 1
DC ANALOG	15	20	12
AC ANALOG	10	11	10
FREQUENCY	4	8	4
DISCRETES	23	51	52
AUDIO –	--	YES	SELECTED

COMPOSITE KNOWN REQUIREMENTS AS TYPICAL OF CLASS

(A) FOR UH60A, AH64, CH47D AND OV–1/ RV–1
(B) FOR C141 AND C130
(C) FOR F15, F16, A10 AND F18

E–9246

TABLE 55. BLACK HAWK (UH60A) PARAMETER LIST - DC ANALOG

PARAMETER	PRODUCTION AIRCRAFT				FLIGHT TEST AIRCRAFT			
	DATA RANGE	SIGNAL RANGE (IN VDC)	RESOLUTION	LIMIT EXCEEDANCE	DATA RANGE	SIGNAL RANGE (IN VDC)	RESOLUTION	LIMIT EXCEEDANCE
Airspeed	30 to 180 Knots	2.25 to 13.5	3.04 Knots	6 08 Knots	0 to 200 Knots	0 to 3.3	(SEE NOTE 1)	
Engine #1 Torque	0 to 150%	0 to 5.277	2.23%	4.46%	0 to 150%	0 to 5.277	2.23%	4.46%
Engine #2 Torque	0 to 150%	0 to 5.277	2.23%	4.46%	0 to 150%	0 to 5.277	2.23%	4.46%
Vertical Acceleration (Load Factor)	-1.5 to 3.5 G's	Undefined	0.16G	0.32G	-3.5 to 5.5 G's	± 2.5	0.125G	0.25 G
Collective Stick Position	0 to 100%	± 6.7	3.2%	6.4%	0 to 100%	0 to -2.5	3.2%	6.4%
Lateral Stick Position	Undefined	DC Analog	Undefined	Undefined	0 to 100%	0 to -2.5	3.2%	6.4%
Longitudinal Stick Position	± 50%	± 7.0	3.2%	6.4%	0 to 100%	0 to -2.5	3.2%	6.4%
Pedal Position	Undefined	DC Analog	Undefined	Undefined	0 to 100%	0 to 5.0	3.2%	6.4%
Stabilator Actuator #1	0 to 6.9 Inches	± 14.07	SEE NOTE 2		0 to 100%	0 to -2.5	1.6%	3.2%
Stabilator Actuator #2	0 to 6.9 Inches	± 14.07			---	---	---	---
Ice Rate	0 to 1.0 Gram/Meter^3	1.0 to 5.0	0.04 Gram/Meter^3	0.08 Gram/Meter^3	NOT ON TEST AIRCRAFT			
Altitude Rate	± 6000 Feet/Min.	± 10	46.8 Feet/Minute	93.6 Feet/Minute	± 10,000 Feet/Min.	± 2.5	39 Feet/Minute	78 Feet/Minute
Vertical Impact Acceleration	± 150G's	DC Analog	Undefined	7.0G's	NOT ON TEST AIRCRAFT			
Lateral Impact Acceleration	± 150G's	DC Analog	Undefined	7.0G's	NOT ON TEST AIRCRAFT			
Longitudinal Impact Acceleration	± 150G's	DC Analog	Undefined	7.0G's	NOT ON TEST AIRCRAFT			
Analog Self Test	0 to 5.1 VDC	0 to 5.1	N/A	N/A	0 to 5.1 VDC	0 to 5.1	N/A	N/A

TABLE 56. BLACK HAWK (UH60A) PARAMETER LIST - AC ANALOG

AC ANALOGS

PARAMETER	PRODUCTION AIRCRAFT DATA RANGE	PRODUCTION AIRCRAFT SIGNAL RANGE	PRODUCTION AIRCRAFT RESOLUTION	PRODUCTION AIRCRAFT LIMIT EXCEEDANCE	FLIGHT TEST AIRCRAFT DATA RANGE	FLIGHT TEST AIRCRAFT SIGNAL RANGE	FLIGHT TEST AIRCRAFT RESOLUTION	FLIGHT TEST AIRCRAFT LIMIT EXCEEDANCE
Heading	0 to 360°	0 to 11.8 VAC, 400 Hz	1.8	2.0°	0 to 360°	0 to 11.8 VAC, 400 Hz	1.0°	2.0°
Roll Attitude	± 1.80°	0 to 11.8 VAC, 400 Hz	1.0°	2.0°	± 180°	0 to 11.8 VAC, 400 Hz	1.0°	2.0°
Pitch Attitude	± 82°	0 to 11.8 VAC, 400 Hz	1.0°	2.0°	± 82°	0 to 11.8 VAC, 400 Hz	1.0°	2.0°
Stabilator Indicator	+10° to -45°	0 to 11.8 VAC, 400 Hz	Undefined		NOT AVAILABLE ON TEST AIRCRAFT			
Spare Synchro		0 to 11.8 VAC, 400 Hz						
Spare Synchro		0 to 11.8 VAC, 400 Hz						
Synchro Self Test	Fixed Reference	11.8 VAC, 400 Hz						
Rotor RPM	0 to 130%	0 to 14,326 Hz	1.52%	3.04%	0 to 130%	0 to 14,326 Hz	2%	4% @100%
Engine #1 RPM (NG)	0 to 110%	0 to 2,349.3 Hz	1.8%	3.6%	0 to 110%	0 to 2,349.3 Hz	1.5% 0.38%	3.0% @100% 0.76% @50%
Engine #2 RPM (NG)	0 to 110%	0 to 2,349.3 Hz	1.8%	3.6%	0 to 110%	0 to 2,349.3 Hz	1.5% 0.38%	30% @100% 0.76% @50%
Spare Frequency								
Frequency Self Test	2400 Hz	2400 Hz			2400 Hz	2400 Hz		

TABLE 57. BLACK HAWK (UH60A) PARAMETER LIST - DISCRETES

DISCRETES

PARAMETER	PRODUCTION AIRCRAFT				FLIGHT TEST AIRCRAFT			
	DATA RANGE	SIGNAL RANGE	RESOLUTION	LIMIT EXCEEDANCE	DATA RANGE	SIGNAL RANGE	RESOLUTION	LIMIT EXCEEDANCE
Altitude (9 Bit Grey Code)	-100 to 50,000 Feet	Lo < 2.5VDC Hi > 9.0VDC	Any Change	Any Change	-100 to 50,000 Feet	Lo < 2.5VDC Hi > 9.0VDC	Any Change	Any Change
SAS/FPS Computer Fault	N/A	Fault=0 to 2VDC (50 msec) Normal=10VDC			NOT MONITORED ON TEST AIRCRAFT			
SAS Warning		Pressure Off=28VDC Pressure On=0VDC			NOT MONITORED ON TEST AIRCRAFT			
Main Fire Detection		Fire=28VDC No Fire=0VDC						
Chip Detection Engine #1		Chips=28VDC No Chips=0VDC						
Chip Detection Engine #2		Chips=28VDC No Chips=0VDC			THESE DISCRETE CHANNELS			
Hydraulic Pressure Engine #1		Pressure Lo=28 VDC Pressure Norm=0VDC			WILL BE USED FOR			
Hydraulic Pressure Engine #2		Pressure Lo=28VDC Pressure Norm=0VDC			RAPID SYSTEM/AIRS			
Hydraulic Pressure APU		Pump On=28VDC Pump Off=0VDC			DATA CORRELATION ON			
Spare #1 (28V)	---	---			TEST AIRCRAFT (RUN NUMBER)			
Spare #2 (28V)	---	---						
Spare #3 (Shunt)	---	---			N/A	---	Any Change	Any Change
Spare #4 (Shunt)	---	---				---		
Event						---		
MRU						---		
PGU	N/A		Any Change	Any Change	N/A	---	Any Change	Any Change

Spares - capability for 24 additional high level discretes

TABLE 58. ADVANCED ATTACK (AH64) HELICOPTER PARAMETER LIST

PARAMETER	SIGNAL TYPE	DATA RANGE	SIGNAL RANGE	COMMENTS
Airspeed	DC Analog	0 to 200 Knots	0 to 10VDC	
Heading	AC Synchro	0 to 360°	0 to 11.6 VAC, 400 Hz	
Pressure Altitude	DC Analog	Undefined	0 to 10VDC	From air data system
Vertical Acceleration	DC Analog	-1.5 to 3.5 G's	Undefined	
Pitch Attitude	DC Analog	Undefined	± 10VDC	
Roll Attitude	DC Analog	Undefined	± 10VDC	
Engine Torque	DC Analog	Undefined	0 to 8VDC	
Rotor RPM	Frequency	0 to 100%	0 to 1348 Hz	
Engine RPM	Frequency	0 to 100%	0 to 1396.76 Hz	
Fire Detection	Discrete	---	---	Switch Closure
Chip Detectors	Discrete	---	---	Switch Closure
Hydraulic System Pressure	Discrete	---	---	Switch closure
Lateral Stick Position	DC Analog	± 4.5 Inches	± 10VDC	
Longitudinal Stick Position	DC	± 5 Inches	± 10VDC	
Collective Stick Position	DC Analog	± 6 Inches	± 10VDC	
Pedal Position	DC Analog	± 4.5 Inches	± 10VDC	
Altitude (9 Bit Grey Code)	Discrete	-100 to 50,000 Feet	Lo 2.5VDC Hi 9.0VDC	
Vertical Impact Acceleration	DC Analog	± 150G's	Undefined	
Lateral Impact Acceleration	DC Analog	± 150G's	Undefined	
Longitudinal Impact Acceleration	DC Analog	± 150G's	Undefined	
Stabilator Position	Synchro		0 to 11.8 VAC, 400 Hz	

TABLE 59.PARAMETER LISTS - SUPER STALLION (CH47D)

Parameter	Signal Type	Signal Range	Accuracy
Airspeed	DC 0-10 V	40-200KTS	$\pm$ 5%
Heading	Synchro	0-360^{o}	3.5^{o}
Altitude	DC 0-10V In Steps (9 Discretes)	-1000 to 2000 ft.	$\pm$ 250 Ft.
Vertical Acceleration	DC Analog	TBD	TBD
Longitudinal Acceleration	DC Analog	TBD	TBD
Lateral Acceleration	DC Analog	TBD	TBD
Pitch	Synchro	1^{o}	TBD
Roll	Synchro	1^{o}	TBD
Engine Torque (L&R)	DC 0-70V	0-150%	$\pm$ 2%
Rotor RPM (L&R)	Frequency	TBD	TBD
Engine RPM (L&R)	Frequency	$\pm$ 2%	TBD
Fire Detection	Discrete	28 VDC	TBD
Chip Detection (L&R)	Discrete	28 VDC	TBD
Hydraulic Pressure	Discrete	28 VDC	TBD
Stick Position Lateral	AC $\pm$ 5V	0-100%	$\pm$ 3%
Stick Position Longitudinal	AC $\pm$ 5V	0-100%	$\pm$ 3%
Stick Position Collective	DC Analog	TBD	TBD
Directional Pedal Position	AC $\pm$ 5V	0 - 100%	$\pm$ 3%
Radar Altimeter	DC 0-14V	0-2000ft	2ft or 2%

TABLE 60. MOHAWK (OV1/RV1) PARAMETER LIST

PARAMETER	SIGNAL TYPE
AIRSPEED	SYNCHRO
HEADING	SYNCHRO
ALTITUDE	GREY CODE, 10 DISCRETES
NORMAL ACCELERATION	DC ANALOG
PITCH ATTITUDE	SYNCHRO
ROLL ATTITUDE	SYNCHRO
ENGINE TORQUE (L & R)	AC ANALOG (STRAIN GAUGE)
PROP RPM (L & R)	FREQUENCY
ENGINE RPM (L & R)	FREQUENCY
LONGITUDINAL CONTROL POSITION OR ELEVATOR POS.	DC ANALOG
LATERAL CONTROL POSITION OR AILERON POS.	DC ANALOG
RUDDER PEDAL POSITION OR RUDDER POS.	DC ANALOG
RADAR ALTITUDE	DC ANALOG
HYDRAULIC PRESSURE (L & R)	AC RATIO
OIL PRESSURE (L & R)	AC RATIO
A/B FLAP POSITION	DC ANALOG
ENGINE FIRE DETECTOR (L & R)	DISCRETE, 28 VDC
ENGINE CHIP DETECTOR (L & R)	DISCRETE, 28 VDC
DC BUS FAULT WARNING (4)	DISCRETE, 28 VDC
FUEL LOW	DISCRETE, 28 VDC
FUEL PUMP (L & R)	DISCRETE, 28 VDC
LANDING GEAR SQUAT SWITCH	DISCRETE, 28 VDC
SPEED BRAKE (2)	DISCRETE, 28 VDC

TABLE 61. C130/C141 AIRCRAFT PARAMETER LIST

SIGNAL TYPE CODES D DISCRETE DC DC VOLTAGE I INTERNAL REF. S SYNCHRO F FREQUENCY	FAA		C130				C141			
		MAXIMUM SAMPLING INTERVAL SEC.	WARNER ROBINS	HAMILTON STANDARD RECOMMENDED SIGNAL	SIGNAL TYPE	AFAIRS "LOOK" INTERVAL SEC.	WARNER ROBINS	HAMILTON STANDARD RECOMMENDED SIGNAL	SIGNAL TYPE	AFAIRS "LOOK" INTERVAL SEC.
TIME	✓	60.0	✓	✓	I	1.0	✓	✓	I	1.0
ALTITUDE (10 DISCRETES)	✓	1.0	✓	✓	D	1.0	✓	✓	D	1.0
AIRSPEED	✓	1.0	✓	✓	DC	1.0	✓	✓	DC	1.0
HEADING	✓	1.0	✓	✓	S	1.0	✓	✓	S	1.0
PITCH ATTITUDE	✓	1.0	✓	✓	S	1.0	✓	✓	S	1.0
ROLL ATTITUDE	✓	1.0	✓	✓	S	1.0	✓	✓	S	1.0
VERTICAL ACCELERATION	✓	0.25	✓	✓	DC	0.04	✓	✓	DC	0.04
LATERAL ACCELERATION	✓	0.25	✓	✓	DC	0.25	✓	✓	DC	0.25
LONGITUDINAL ACCELERATION			✓	✓	DC	0.25	✓	✓	DC	0.25
PITCH TRIM	✓	[illegible]	✓	✓	DC	2.0	✓	✓	DC	2.0
PITCH CONTROL	✓	1.0		✓	DC	1.0		✓	DC	1.0
ROLL CONTROL	✓	1.0		✓	DC	1.0		✓	DC	1.0
YAW CONTROL	✓	0.50		✓	DC	0.50		✓	DC	0.50
THRUST	✓	4.0								
(C141) EPR (4)							✓	✓	S	4.0
(C130) N2 (4)			✓	✓	F	4.0				
(C130) TORQUE (4)			✓	✓	S	4.0				
(C130) BETA (4)			✓	□	DC					
FLAP POSITION	✓	[illegible]	✓	✓	DC	2.0	✓	✓	DC	2.0
REVERSE THRUST (4)	✓	4.0					✓	✓	D	4.0
GEAR POSITION			✓	✓	D	1.0	✓	✓	D	
CONDITION LEVER (4)			✓	✓	D	1.0				
THROTTLES (4)			✓	□	DC	1.0				
RADIO KEYING			✓	✓	D	1.0	✓	✓	D	1.0
AC BUS VOLTAGE (2)			✓	✓	D	1.0		✓	D	1.0
HYDRAULIC PRESSURE (2)			✓	✓	D	1.0		✓	D	1.0
SPOILER	✓	1.0					✓	✓	D	1.0

✓ - Recommended by HS In Addition to AF Para's.
□ - Not Recommended by HS

To reflect current Air Force safety center preliminary requirements for mishap investigation, the following parameters are added to the original listing above.

Engine Fuel Pressure (4) Discrete	Engine Fire Warning (4) Discrete
Engine Fuel Flow Rates (4) AC Analog	Engine Oil PRessure (4) Discrete
Fuel Quantity (4) DC Analog	Hydraulic System Warning (4) Discretes
Engine Temperatures (4) Discrete	N_1 & N_2 For Turbo Jet (8) Frequency

Plus ten (10) miscellaneous discretes for added fault warning data.

TABLE 62. FLIGHT PARAMETERS FOR THE FDR SYSTEM IN THE E-2B AIRCRAFT

PARAMETER	SAMPLE RATE PER SEC	SIGNAL TYPE
Elapsed Flight Time	2	Internal
Pitch Attitude	1	Synchro
Roll Attitude	2	Synchro
Magnetic Heading	1	Synchro
RPM #1 (2)	1	Tachogenerator Frequency
RPM #2 (2)	1	Tachogenerator Frequency
Horsepower #1	1	Torquemeter DC Analog
Horsepower #2	1	Torquemeter DC Analog
Fuel Flow #1	1	Magnesyn (AC Analog)
Fuel Flow #2	1	Magnesyn (AC Analog)
Power Lever Position #1	1	DC Potentiometric Transducer
Power Lever Position #2	1	DC Potentiometric Transducer
Vertical Acceleration	4	DC Potentiometric Transducer
Indicated Airspeed	1	DC Potentiometric Transducer
Pressure Altitude	2	DC Potentiometric Transducer
Elevator Position	1	DC Potentiometric Transducer
Rudder Position	1	DC Potentiometric Transducer
Aileron Position	1	DC Potentiometric Transducer
Pitch Trim	1	DC Potentiometric Transducer
TIT #1	1	Thermocouple
TIT #2	1	Thermocouple
Cabin Temperature	1	Thermistor
Flap Position	1/2 (1)	Relay ON/OFF Discrete
Generator #1	1/2 (1)	Relay ON/OFF Discrete
Generator #2	1/2 (1)	Relay ON/OFF Discrete
Automatic Flight Control System	1/2 (1)	Relay ON/OFF Discrete
Cabin Pressure Warning	1/2 (1)	Switch ON/OFF Discrete

TABLE 63. FLIGHT PARAMETERS FOR THE FDR SYSTEM IN THE E-2B AIRCRAFT (CONTINUED)

PARAMETER	SAMPLE RATE PER SEC	SIGNAL TYPE
Flight Hyd. Pressure	1/2[(1)]	Switch ON/OFF Discrete
Combined Hyd. Pressure	1/2[(1)]	Switch ON/OFF Discrete
Fire Warning #1	1/2[(1)]	Switch ON/OFF Discrete
Fire Warning #2	1/2[(1)]	Switch ON/OFF Discrete
Fuel Low Warning #1	1/2[(1)]	Switch ON/OFF Discrete
Fuel Low Warning #2	1/2[(1)]	Switch ON/OFF Discrete
Oil Quantity Warning #1	1/2[(1)]	Switch ON/OFF Discrete
Oil Quantity Warning #2	1/2[(1)]	Switch ON/OFF Discrete
Synchro Calibration	1	Internal
Analog Calibration	1	Internal
Pilot's ICS	Continuous	Audio
Copilot's ICS	Continuous	Audio

NOTE: (1) Once every other second.

TABLE 64. F-18 PARAMETER LIST

Parameter	Number of Bits	Data Bits	Resolution	Limit Exceedance Value
Vertical Acceleration	Bits 8	8 Thru 15	4 Ft/Sec/Sec	8 Ft/Sec/Sec
Pitch Attitude	Bits 8	8 Thru 15	1.40625 BAMS	2.813 BAMS
Roll Attitude	Bits 8	8 Thru 15	1.40625 BAMS	2.813 BAMS
EGT LT	Bits 8	7 Thru 14	8 DEG C	16 DEG C
EGT RT	Bits 8	7 Thru 14	8 DEG C	16 DEG C
Main Fuel Flow LT	Bits 6	9 Thru 14	128 LBS/Hr	256 Lbs/Hr
Main Fuel Flow RT	Bits 6	9 Thru 14	128 Lbs/Hr	256 Lbs/Hr
Hi Pr Rotor Speed Lt	Bits 7	8 Thru 14	128 RPM	256 RPM
Hi Pr Rotor Speed RT	Bits 7	8 Thru 14	128 RPM	256 RPM
Low PR Rotor Speed LT	Bits 8	7 Thru 14	128 RPM	256 RPM
Low PR Rotor Speed RT	Bits 8	7 Thru 14	128 RPM	256 RPM
LT Stab Position	Bits 7	9 Thru 15	.703125 BAMS	1.406 BAMS
RT Stab Position	Bits 7	9 Thru 15	.703125 BAMS	1.406 BAMS
Baro Corrected Press Alt	Bits 13	7 Thru 19*	64 Feet	128 Feet
Left Tef Position	Bits 7	8 Thru 14	.351563 BAMS	.703 BAMS
Right Tef Position	Bits 7	8 Thru 14	.351563 BAMS	.703 BAMS
Inboard Lef Position	Bits 7	8 Thru 14	.352563 BAMS	.703 BAMS
Fuel Quantity Total Int	Bits 6	9 Thru 14	512 Lbs	1024 Lbs
Power Lever Angle Lt	Bits 9	7 Thru 15	.703125 BAMS	1.406 BAMS
Power Lever Angle RT	Bits 9	7 Thru 15	.703125 BAMS	1.406 BAMS
LT Inlet Temp	Bits 8	8 Thru 15	2 DEG C	4 DEG C
RT Inlet Temp	Bits 8	8 Thru 15	2 DEG C	4 DEG C
Magnetic Heading	Bits 10	6 Thru 15	.351563 BAMS	.703 BAMS
True AOA	Bits 7	9 Thru 15	.703125 BAMS	1.406 BAMS
Ambient Temperature	Bits 11	5 Thru 15	1 DEG R	2 DEG R
Mach Number	Bits 8	7 Thru 14	.015625 MACH	.0314 Mach
Indicated Air Speed	Bits 8	7 Thru 14	4 Knots	8 Knots
Total Temperature	Bits 11	5 Thru 15	1 DEG R	2 DEG R
Pitch Takeoff Trim Set	Bits 1		DISCRETE	ANY CHANGE
Maneuver Flaps Off	Bits 1		DISCRETE	ANY CHANGE

BAMS - Binary Angular Measurement System
TEF - Trailing Edge Flap
LEF - Leading Edge Flap

TABLE 65. F-18 PARAMETER LIST (CONTINUED)

Parameter	Number of Bits	Data Bits	Resolution	Limit Exceedance Value
Oil Warning Hyd System 1	Bits 1		DISCRETE	ANY CHANGE
Oil Warning Hyd System 2	Bits 1		DISCRETE	ANY CHANGE
Oil Warning Lt AMAD	Bits 1		DISCRETE	ANY CHANGE
Oil Warning RT AMAD	Bits 1		DISCRETE	ANY CHANGE
Oil Warning APU	Bits 1		DISCRETE	ANY CHANGE
Generator Warning Lt	Bits 1		DISCRETE	ANY CHANGE
Auto Flight Control on Heading Hold	Bits 1		DISCRETE	ANY CHANGE
Auto Flight Control on Attitude	Bits 1		DISCRETE	ANY CHANGE
Auto Flight Control on Baro Altitude	Bits 1		DISCRETE	ANY CHANGE
Auto Flight Control on Radar Altitude	Bits 1		DISCRETE	ANY CHANGE
Engine Start On	Bits 1		DISCRETE	ANY CHANGE
Rudder Second Fail	Bits 1		DISCRETE	ANY CHANGE
Aileron Second Fail	Bits 1		DISCRETE	ANY CHANGE
Elevator Second Fail	Bits 1		DISCRETE	ANY CHANGE
Cockpit Temp Control Fail	Bits 1		DISCRETE	ANY CHANGE
* 3 Thru 15 on Serial Link				

The data storage requirements for class C aircraft were determined to be one hundred thirty one (131) kilobits as reported in Section 2.5 of this report as determined from actual data from a fighter simulator test. The impact of combining Class A and Class C aircraft on size, weight, unit cost, reliability and maintainability is summarized in Table 66.

The Class A requirements are as obtained from current data on the Army AIRS FDR program. The Class C data is discussed in Section 2.7 except for the maintainability number as estimated herein. The AIRS FDR size is adjusted downward from previous estimates to reflect expected improvements in electronic component integration in the time frame assumed for the Air Force program. The Army FDR concept includes a 150g shock requirement on the basic unit such that crash impact accelerations can be recorded by the system up to this level. This has a small weight impact on the design (approximately 0.5 pounds) that would be added to the combined system weight. In addition, the resulting mechanical construction would be such that unit disassembly and module replacement at the intermediate maintenance level would be more time consuming. The result is a slightly higher overall maintainability number for the combined system than for either requirement.

The principle differences betweeen Class A and C requirements that result in a penalty to Class A but not to C due to combining are in unit cost and reliability. These are due to increased signal conditioner and connector complexity in Class C and the requirement for a larger data storage memory.

Another apparent difference between A and C that contributes to the penalty to A when combining are the increased signal conditioning complexity due to C causing a heavier package, more interconnections and one added box connector (1 pound delta).

The apparent closeness of the Class A and C CSFDR in maintainability is due to two off-setting affects. The Class A number should have been significantly lower than C due to the reliability differences alone. However, the time to repair a Class A unit at the intermediate level is greater as discussed above.

The maintainability numbers were prepared based on the estimations prepared in the published AIRS report using the FDR reliability numbers alone and multiplying a three (3) hour depot level repair time to the shop repair rates. A one (1) hour repair time was assumed at the intermediate level for the Class C FDR as compared to two (2) hours for a Class A unit.

Conclusions

Class A and C aircraft are candidates for system level standardization except some Class C aircraft may be excluded because of mission requirements - primarily over water operations requiring a deployable data module. Class B aircraft have unique requirements which would allow standardization with A and C only on selected components/modules. Module standardization possibilities are summarized in Table 67.

TABLE 66. IMPACT OF COMBINING CLASS A & C REQUIREMENTS

(BASED ON 1982 APPLICATION)

	A	C	ESTIMATED COMBINED
SIZE	164 IN^3	177.5 IN^3	177.5 IN^3
WEIGHT	8.5 LBS	9.5 LBS	10.0 LBS
UNIT COST	0.8	1.0	1.0
RELIABILITY	10,000 HRS (MTBF)	8,300 HRS (MTBF)	8,300 HRS (MTBF)
MAINTAINABILITY*	0.6 HRS/1,000 FLIGHT HOURS	0.6 HRS/1,000 FLIGHT HOURS	0.72 HRS/1,000 FLIGHT HOURS
*LINE INTERMEDIATE DEPOT			

NOTE: USING AVAILABLE COMPONENT TECHNOLOGY IMPROVEMENTS SUCH AS GATE ARRAYS AND LEADLESS CARRIER CHIPS WHERE PRACTICAL.

E–9247

TABLE 67. TRI-SERVICE COMPONENT/MODULE STANDARDIZATION

MODULE	EXPLANATION	DEGREE OF STANDARDIZATION POSSIBLE
Aircraft Characterizing Devices	Passive or active element that can be read by the FDR for aircraft type/model/ serial number	Complete-External to FDR Unit(s)
Power Supplies	(Larger capacity split supplies required for Group B)	Complete for A & C
Processor Arrays	Microprocessor, functional memories and I/O. (Program memory assumed loaded in RAM at power on from the non-volatile data memory)	Complete for A & B and C. (Assuming data processing separate from voice). For B a separate second micro-processor of lesser capability would be in the remote memory unit
Mass Memory Storage Interface	Mass memory control card	Complete for A & C. B would require a complex interface for voice & data
Analog Signal Conditioners and A/D	Synchro, AC, DC, frequency, discrete, & Analog to Digital Converter	Complete for A, B & C although some overhead would be incurred in A & C by designing for B also
Digital Receiver or Transceiver	Special digital input ports or dedicated busses between FDR units	None (Part of a module in terms of real estate)
Mil-Std-1553	Dual interface bidirectional or passive	Complete as standard chip sets. (Part of a module in terms of real estate
Survivable Memory Module	(Much larger memory module in size and capacity for B-10 to 100 times A or C)	Complete for A & C with some overhead to A

The level of module standardization shown is relatively independent of whether the technology is current or future. Future technology gains in large scale integration in electronic components will tend to minimize the amount of overhead cost, size and reliability but will not change the degree of module or system standardization estimated.

3.5 MAINTENANCE RECORDER/MONITOR

The candidate for functional expansion in the maintenance area include engine health monitoring, airframe health monitoring and flight control monitoring. The engine health monitoring includes engine history, thermodynamic performance and mechanical health. The airframe health monitoring includes acceleration load history and structural integrity monitoring.

Engine Health Monitoring

Engine monitoring diagnostics and prognostics involves both thermodynamic performance and mechanical condition monitoring. An integral part of engine monitoring is usage factor (life history) recording.

Modular engine diagnostics use gas path performance analysis in order to isolate thermodynamic engine performance problems to the particular engine module requiring service. The engine condition monitoring system obtains data on engine parameters under stable flight operating conditions. This data and selected mechanical condition information is analyzed by the system to assist in determining repair action required.

In general, engine diagnostics is a cost versus degree of capability tradeoff whicn has not been satisfactorily resolved in the military. Certainly, for a future system the degree of capability will improve due to advances in sensors, electronics and software relative to cost. It is assumed here that two broad levels of diagnostic capability are probable with the on-engine alternative being more far term and more sophisticated. This approach is currently being studied and developed by the industry. One engine manufacturer is currently studying requirements versus cost in an attempt to optimize the capability versus cost factor. An intermediate level of capability, aimed primarily at the principle known/sought problems, is studied further herein as an alternative nearer term system. Detail treatment of the on-engine configurations is considered to be beyond the scope of this study along with the related detail comparative analysis of the on engine/off engine alternatives.

The current trend in the military engine area is toward an integral on-engine capability for all of the above areas. The current Air Force engine monitoring program on the F100 engine called EDS (Engine Diagnostic System) is typical of the state-of-the-art in this area. One alternative in the EDS program was the use of on engine multiplexers which fed an airframe mounted computer and recording system. The engine multiplexer was in fact a sensor, signal conditioner and local processor that by itself performed the life history

function and first level software on data being shipped to the airframe computer. The second generation engine mounted device is expected to be completely self contained and capable of performing all engine life and diagnostic functions.

It is expected that the engine unit will hand off current cumulative life and diagnostic data to an airframe flight recording function via a 1553 or dedicated bus structure, (See Figure 27). Certain critical readouts, particularly engine stress factors, may still reside on the engine unit while routinely taken data can be stored in the CSFDR and transferred to a common GSE set for further flight line processing and display advisories.

Perhaps the most important factor favoring an integral engine monitoring capability is that the cumulative engine history stays with the engine. If the records are not on-engine, major logistics problems are involved in insuring that the engine data is identified and transferred as the engine moves around the inventory.

Perhaps the most important factor against on-engine mounting is the cost penalty of on versus off engine mounting and the fact that multi-engine aircraft requires one unit per engine compared to one airframe mounted unit servicing all engines. However, technology gains are tending to reduce this penalty.

Depending on aircraft size, the installed weight of integral engine units may be less than running a relatively large number of wires from the engine junction box to the desired airframe location.

The capability of this system is expected to be at or near the level currently predicted for EDS.

A block diagram of a CSFDR system with an intermediate level (off engine) engine monitoring is shown in Figure 28. Figure 29 shows the parameters required for monitoring the P&W F100 Engine. Figure 30 shows the parameters required for monitoring the GE TF34 engine. This system is capable of performing the life history function; however, absorbtion of this function would impact the logistics of tracking engine history because the data would no longer be attached to and move with the engine when it is removed from the airframe.

A detail parameter list for the P&W F100 engine is shown in Table 68 plus the signals available from the CSFDR and the additions required to be added for engine condition monitoring. FTIT is repeated because the higher accuracy required for engine diagnostics requires interfacing directly with thermocouple signals which are not handled by the CSFDR standard configurations.

Adding the engine conditioning monitoring capability for twin engine aircraft requires adding fourteen (14) channels of low level, high accuracy signal conditioning thermocouples and strain gages, four (4) channels of DC signal conditioning, two (2) accelerometer signal conditioners with narrow pass band tracking filters for N_1 and N_2 tracking and fourteen (14) discretes.

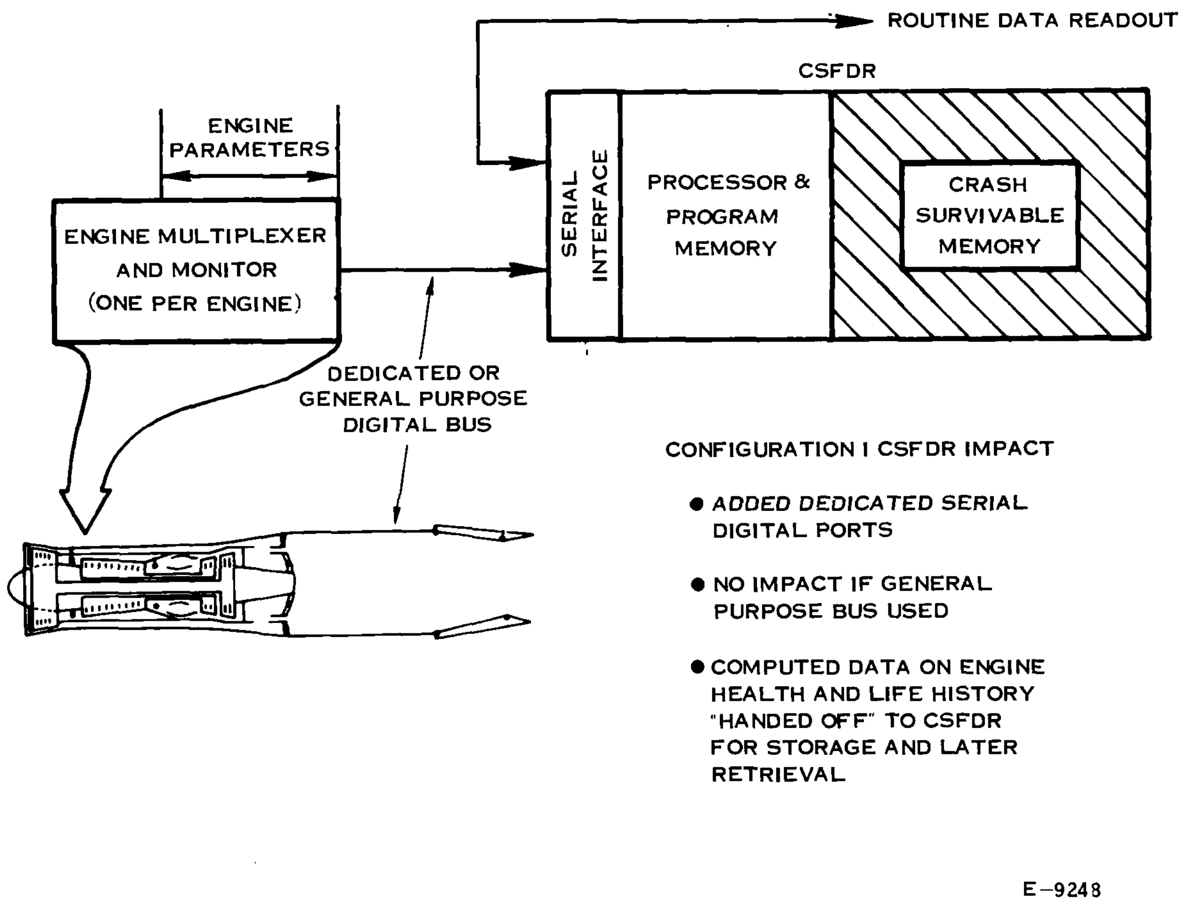


FIGURE 27. ADVANCED ON-ENGINE HEALTH MONITOR BLOCK DIAGRAM

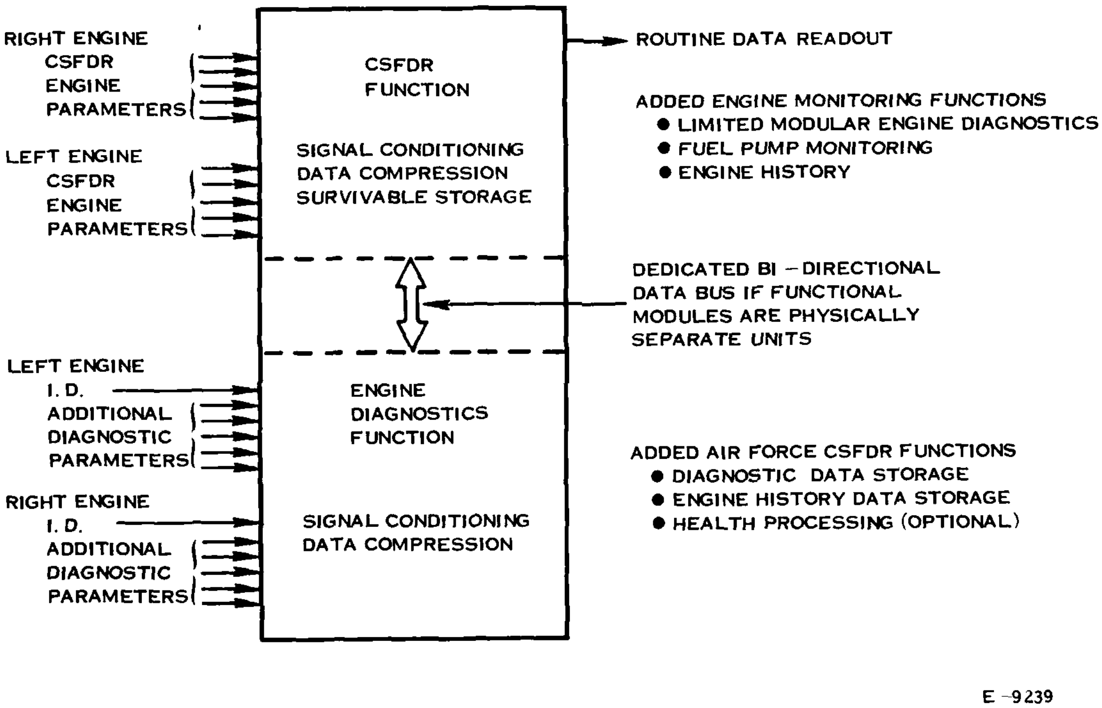


FIGURE 28. INTERMEDIATE LEVEL ENGINE MONITOR

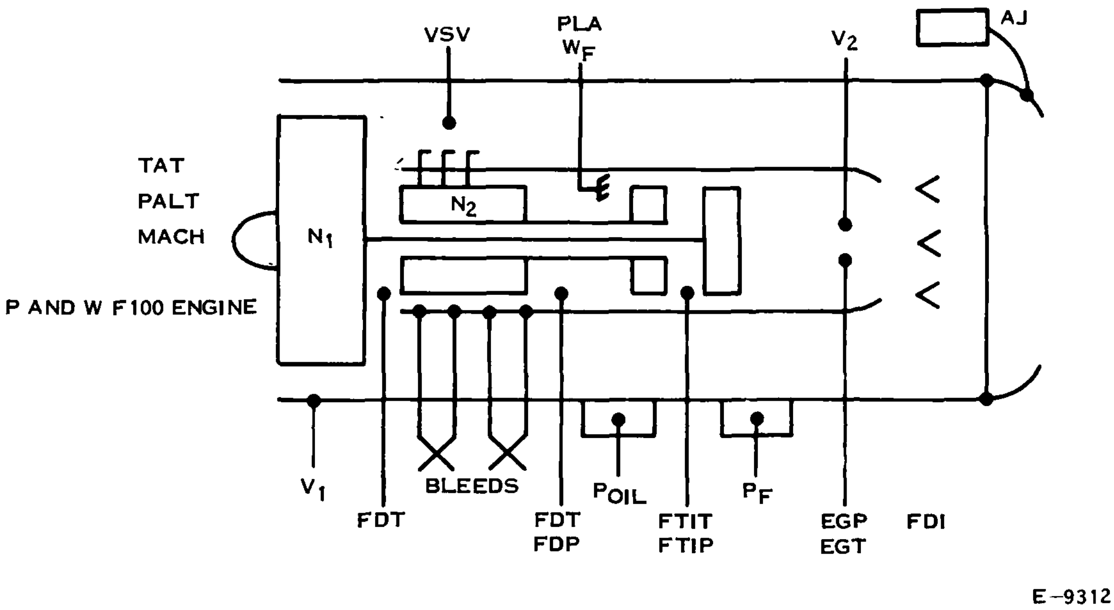


FIGURE 29. INTERMEDIATE ENGINE MONITORING CAPABILITIES—F100 ENGINE

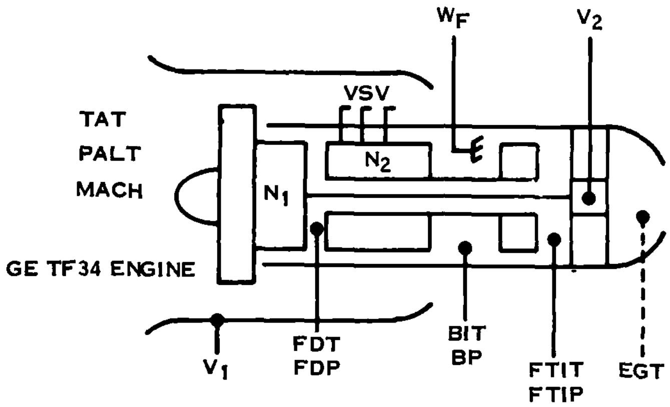


FIGURE 30. INTERMEDIATE ENGINE MONITORING CAPABILITIES-TF 34 ENGINE

TABLE 68. PRELIMINARY INTERMEDIATE LEVEL ENGINE MONITORING PARAMETERS (F100 ENGINE)

	GAS PATH	AVAILABLE AF CSFDR LIST	ADDITIONS FOR ENGINE MONITORING
TAT	TOTAL AIR TEMPERATURE		X
PALT	PRESSURE ALTITUDE	X	
MACH	MACH NUMBER	X	
N1	FAN SPEED	X	
N2	COMPRESSOR SPEED	X	
FDP	FAN DISCHARGE PRESSURE		X
FDT	FAN DISCHARGE TEMPERATURE		X
BIT	BURNER INLET TEMPERATURE		X
BP	BURNER PRESSURE		X
FTIT	FAN TURBINE INLET TEMPERATURE	X	X (1)
FTIP	FAN TURBINE INLET PRESSURE		X
EGT	EXHAUST GAS TEMPERATURE	X	X (2)
W_F	FUEL FLOW	X	
PLA	POWER LEVER ANGLE	X	
AJ	NOZZLE AREA	X	
B	BLEED DISCRETES		X
VSV	VARIABLE STATOR VANE ANGLE		X
MECHANICAL			
V1, V2	VIBRATION (2 ORTHOGONAL LOCATIONS)		X
P_F	FUEL PUMP DIFFERENTIAL PRESSURE OR	X	X (2)
	DISCHARGE PRESSURE	X	
P_{OIL}	MAIN ENGINE OIL PRESSURE	X	(2)
	OTHER DISCRETES AS AVAILABLE		X (10)

E-9245

(1) REPEATED BECAUSE OF HIGHER ACCURACY REQUIREMENT
(2) ADD FOR ANALOG OF PRESSURE INSTEAD OF DISCRETE

The general engine condition monitoring scope is assumed to be similar to current commercial aircraft programs combined with the EMUX prototype functions in the F100 EDS program as described below.

The engine condition airborne processing consists of filtering and sensed signals, rejection of wild points and determining thermodynamic stable conditions before taking a set of data for storage. The stored data is ground processed to determine the engine condition. Two hundred forty (240) bits of data are required for each set of data on an engine. In addition periodic and any out of limit data is added to the data output for mechanical condition. Assuming a twin engine aircraft and twenty (20) sets of data for each engine, the storage memory capacity required is less than ten (10) kilobits.

The Engine history recorder function consists of accumulating the total engine operating time, the hot section operating time, number of engine starts and number of fatigue cycles and critical events such as hot starts for readout by flight line personnel.

Airborne processing needs for these engine monitoring functions is expected to be a fraction of basic CSFDR requirements.

Air Frame Health

The current airframe monitoring consists of load factor monitoring on every airframe and structural integrity monitoring on typically 1 out of 5 to 10 aircraft. The load factor monitoring is basically a counting accelerometer function which is used to institute inspections and repair actions. The structural integrity monitoring programs track typical aircraft operation and determine the effect on structural integrity or airframe life. The analysis results may be used to modify structures or operation to extend life or determine maintenance requirements. Figure 31 illustrates the structural monitoring data flow along with the modification to the data flow which would occur from the expanded flight data recorder approach.

This structural monitoring system function and parameters are based on the current F15 system which is the most sophisticated system of the aircraft studied. A similar implementation of the present level system was assumed except for the airborne system which in this case does data compression to minimize the data quantity. The airborne data quantity stored must be bounded to make a solid state airborne memory practical. A more advanced structural monitoring system can be concepted and airborne data reduction performed which would reduce the data storage requirements by orders of magnitude. This approach would perform the fatigue load computations and output delta values to the ground stored data files for each airframe. This approach would however limit the use of data for other general purposes since the general character of the flight data would not reach the ground analysis system. The initial uncompressed data is assumed to be the twenty-five (25) hours of F15 data. The F16 and A10 systems record for fifteen (15) hours.

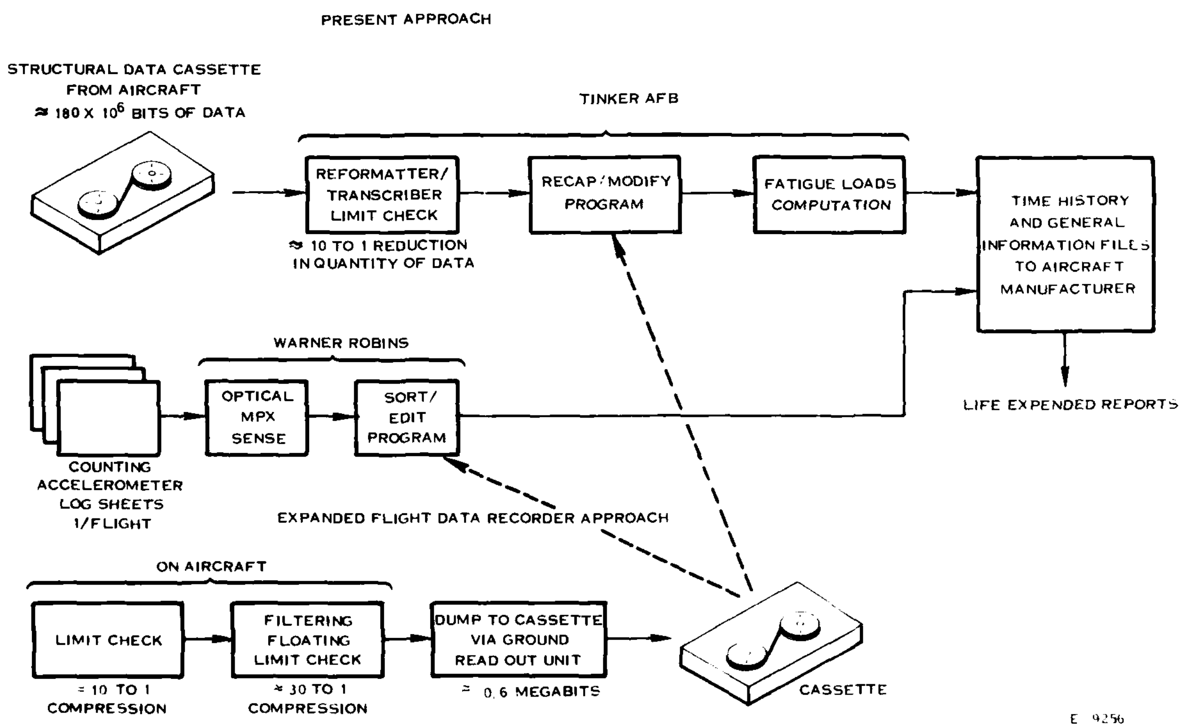


FIGURE 31. STRUCTURAL MONITORING SYSTEM DATA FLOW

A typical structural monitoring parameter list is shown in Table 69. The signals available from the CSFDR as well as the additions and where applicable increases in CSFDR sample rates that are required for the CSFDR function are also listed.

The affect of adding structural monitoring to the CSFDR is the addition of eleven (11) input signals (which may be analog or digital depending upon the aircraft), increased sampling rate on some CSFDR signals, an additional 600 kilobits of data memory and requires the equivalent processing capacity of the CSFDR function (approximately 40% of 8085 or equivalent processing time). The load factor function would have negligible impact on processing and storage.

Flight Control Monitoring

The three airframes studied, (A10, F15 and F16) are representative of typical current aircraft flight control types. The A10 has a mechanical control system with a stability augmentation system. The F15 has a Control Augmentation System connected to mechanical controls. The F16 is a fly-by-wire system with a high level of flight control system monitoring and fault data output.

The signal list for monitoring the A10 flight controls is shown in Table 70. The CSFDR signals cover all the available signals in the flight control except the SAS mode discretes which should be added for flight control monitoring.

The recommended F15 flight control monitoring parameters are listed in Table 71. The CSFDR monitors all the readily available signals from the flight control. Additional intermediate signal faults in the CAS electronics and sensors can be made available from the flight control to further localize control system faults. These are included as ten (10) discretes in the referenced table.

The F16 fly-by-wire system inherently provides a serial digital data word which contains diagnostic discretes which isolate faults within the control. The additional discretes covering the external influences on the control system operation are as shown in Table 72.

The baseline CSFDR contains almost all the available parameters listed in Tables 70, 71 and 72. Four (4) additional discretes are added to the A10 list and ten (10) discretes added for the F15 application.

A significant flight control monitoring capability can therefore be obtained with very little penalty to the CSFDR function. The fault data would be stored routinely in the CSFDR and read out by common GSE. It is assumed that the related diagnostic logic for flight control monitoring would be located off-board in the GSE therefore no significant on-board control monitor processing overhead is required in the CSFDR function.

TABLE 69. TYPICAL STRUCTURAL MONITORING PARAMETER LIST

PARAMETER	BASIC CSFDR	ADDED SIGNAL	CSFDR SAMPLE RATE INCREASE
ALTITUDE	X		
TRUE AIRSPEED	X		
ANGLE OF ATTACK	X		X10
WEAPON COUNT		X	
VERTICAL VELOCITY		X	X3
GUN FIRE	X		
VERTICAL ACCELERATION	X		
PRIMARY CONTROL SURFACE POSITIONS	3	3	X3
FUEL QUANTITY	X		
SPEED BRAKE	X		
WHEEL POSITION	X		
PITCH RATE	*	X **	
ROLL RATE	*	X **	
YAW RATE	*	X **	
LATERAL ACCELERATION		X **	
LONGITUDINAL ACCELERATION		X **	

*CSFDR USES DERIVED RATES

**EITHER SENSORS MUST BE ADDED FOR ASIPS OR DATA MADE AVAILABLE FROM THE FLIGHT CONTROL /INS

E-9253

TABLE 70. A10 FLIGHT CONTROL MONITORING PARAMETERS

	TYPE	COMMENTS
CSFDR SIGNALS		
ELEVATOR DISENGAGE	DISCRETE	SEE PHASE I REPORT
LEFT ELEVATOR JAM	DISCRETE	TABLE I
RIGHT ELEVATOR JAM	DISCRETE	
AILERON DISENGAGE	DISCRETE	
LEFT AILERON TAB WARNING	DISCRETE	
RIGHT AILERON TAB WARNING	DISCRETE	
LEFT AILERON TAB SHIFTER	DISCRETE	
RIGHT AILERON TAB SHIFTER	DISCRETE	
LEFT AILERON JAM	DISCRETE	
RIGHT AILERON JAM	DISCRETE	
LEFT ENGINE HYDRAULIC PRESSURE	DISCRETE	
RIGHT ENGINE HYDRAULIC PRESSURE	DISCRETE	
LEFT HYDRAULIC SYSTEM SHUTOFF VALVE	DISCRETE	
RIGHT HYDRAULIC SYSTEM SHUTOFF VALVE	DISCRETE	
PITCH SAS	DISCRETE	
YAW SAS	DISCRETE	
RECOMMENDED ADDITIONAL SIGNALS		
SAS MODE SELECTION DISCRETES	4 DISCRETES	

E–9300

TABLE 71. F15 FLIGHT CONTROL MONITORING PARAMETERS

BASIC FDR PARAMETER	SIGNAL TYPE	COMMENTS
HYDRAULIC PRESSURES		
LEFT A	DISCRETE	ALL HYDRAULIC PRESSURES ARE MONITORED BY CSFDR. SOME OF THOSE LISTED MAY NOT HAVE ANY FLIGHT CONTROL IMPLICATIONS
LEFT B	DISCRETE	
RIGHT A	DISCRETE	
RIGHT B	DISCRETE	
UTILITY A	DISCRETE	
UTILITY B	DISCRETE	
ELECTRICAL POWER		
LEFT AC GEN	DISCRETE	
RIGHT AC GEN	DISCRETE	
LEFT DC GEN	DISCRETE	
RIGHT DC GEN	DISCRETE	
EMERGENCY DC	DISCRETE	
CAS YAW ENGAGE	DISCRETE	CSFDR MONITORED – DISENGAGED IS INOPERATIVE OR DISENGAGED
CAS ROLL ENGAGE	DISCRETE	
CAS PITCH ENGAGE	DISCRETE	
PITCH RATIO LINK	ANALOG	
RECOMMENDED ADDITIONS		
ADD INTERMEDIATE POINT FAULT LOCATION IN THE CAS SENSORS & ELEC–TRONICS	10 DISCRETES	USE OF THE FAULT LOCATION DISCRETES MAY REQUIRE ADDED INTERNAL CAS ISOLATION CIRCUITRY FOR FAILURE PROTECTION REASONS

E–9252

TABLE 72. F16 FLIGHT CONTROL MONITORING PARAMETERS

BASIC FDR SIGNALS	SIGNAL TYPE	COMMENTS
SERIAL DIGITAL FAULT WORD	MANCHESTER BI-PHASE	CONTAINS 64 DIAGNOSTIC DISCRETES - SEE TABLES 31, 32, 33
MAIN GENERATOR FAULT	DISCRETE	SEE TABLE 2
EMERGENCY GENERATOR FAULT	DISCRETE	
FLIGHT CONTROL BATTERY DISCHARGE	DISCRETE	
SECOND DC CONVERTER FAIL	DISCRETE	
HYDRAULIC PRESSURE A	DISCRETE	
HYDRAULIC PRESSURE B	DISCRETE	
RECOMMENDED ADDITIONS TO BASIC CSFDR NONE		

E-9251

3.6 INTEGRATED CSFDR/MAINTENANCE MONITORING SYSTEM DESCRIPTION

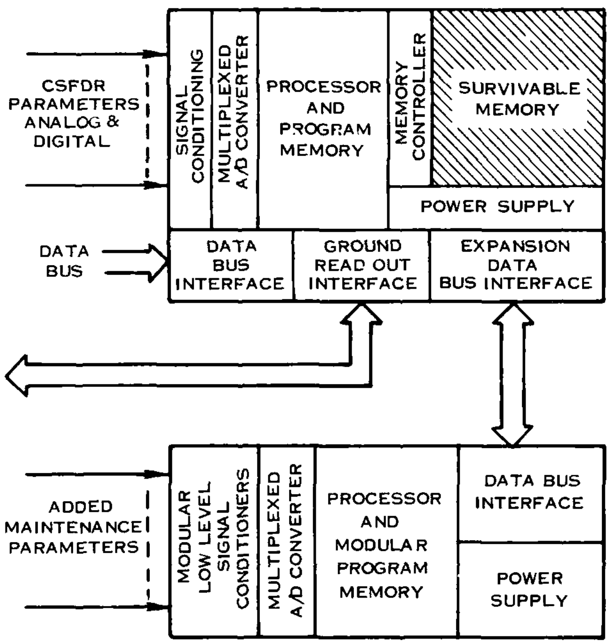
Expansion of the CSFDR into maintenance monitoring functions as described in Paragraph 3.5 can be accomplished by taking advantage of the signal conditioning, processing and data storage capability of a CSFDR defined for mishap investigation support. Engine monitoring functions can be overlaid on the CSFDR with resultant significant economies. However, the future engine monitoring function will likely be performed by an engine mounted diagnostic and multiplexing system that would feed data to the CSFDR for storage and readout. The current airframe monitoring function can also be accommodated in an expanded CSFDR.

For new aircraft installations where CSFDR, structural integrity and cumulative load factor recording are specified, there appears to be no reason why these functions would not be integrated.

The structural integrity function shares many common parameters with a CSFDR and the load factor (g) counting function can be totally absorbed by a CSFDR with practically no penalty. Structural integrity recording on current inventory aircraft is applied in one out of 5 to one out of 10 aircraft. However, the wiring is generally carried in all aircraft as well as many of the added sensors. For those aircraft not needing structural recording, the recording unit is left out. In an integrated system, the overhead carried on aircraft will be reduced since more of the sensors will become standard. Integration of many functions may reduce electronic equipment overhead to one or two printed circuit cards for structural monitoring which could be removed or, at the Air Force's option, left in the system. With reduced per aircraft overhead, it may be advantageous to initiate 100% structural integrity monitoring particularly if the integrated approach addresses the problem of significantly reducing the data bulk prevalent in current generation tape systems.

Flight control monitoring can be added with practically no penalty for the scope as assumed in paragraph 3.5 since nearly all the data is being accummulated in the basic CSFDR.

Figure 32 shows the recommended configuration for a combined CSFDR and maintenance monitoring system. This configuration provides a CSFDR unit and a maintenance expansion unit which are linked together with a data bus. This configuration permits standardization of the CSFDR for a wide range of fighter, attack and trainer aircraft. The CSFDR signal complement and processing is expected to be standardized specifically for mishap investigation with a fixed mix of signal conditioning capability plus expansion. Specialized signal conditioning for monitoring functions are added in the proper mix in the add-on module/unit. The expansion parameters in engine condition monitoring and structural monitoring are engine type and airframe type dependent respectively and are more subject to change as time goes on. The two unit configuration can provide life cycle cost advantage of a common CSFDR unit used over a family of aircraft mated via a standard digital interface to



CSFDR

- STANDARDIZED FIGHTER, ATTACK & TRAINER CONFIGURATION
- FIXED REQUIREMENTS
- UNIT HARDWARE DESIGN TRANSPARENT TO AIRCRAFT TYPE
- CSFDR SIGNALS REQUIRED BY MAINTENANCE FUNCTION SUPPLIED TO EXPANSION UNIT
- CSFDR PROVIDES PROTECTED STORAGE

MAINTENANCE EXPANSION

- MODULAR DESIGN
- HIGHLY FLEXIBLE SIGNAL CONDITIONER COMPLIMENT
- CARDS & SOFTWARE CUSTOMIZED FOR EACH AIRCRAFT REQUIREMENT

E-9313

FIGURE 32. RECOMMENDED CSFDR/MAINTENANCE MONITORING SYSTEM CONFIGURATION

a maintenance module that is individually tailored for each aircraft type. The monitoring system adds only the signal conditioning and processing needed for each application and takes maximum advantage of the CSFDR input handling and data storage media.

The CSFDR maintenance expansion requirements are listed in Table 73. The added signals are unique in terms of signal conditioning. Very low level DC and vibration signal conditioning are not part of a basic CSFDR. The memory requirements for the combined system can be supplied by the one (1) megabit bubble memory system expected to be available for incorporation into a Configuration I CSMU in the 1985 time frame. Processing needs for the maintenance functions are 200% of current estimated CSFDR needs. However, a single future processor could easily handle the entire workload. The impact of combining maintenance monitoring functions in a single unit CSFDR or a two box system is summarized in Table 74. There are size, weight and cost advantages of combining CSFDR and maintenance functions in a single unit as shown. However, the gains are minor in cost and weight with the apparent cost gain expected to be more than offset by having the separate CSFDR unit a common inventory item.

The effects on the basic CSFDR of adding maintenance as a separate modular function are incorporation of a digital communication port on the unit, increased sample rate for some signals (or duplication of signals in maintenance module), increased A/D accuracy for some signals and increased processor workload to service I/O for the maintenance module. These additions are within 2% of the estimated basic CSFDR unit cost and are within the limits of estimating accuracy in this study.

TABLE 73. CSFDR MAINTENANCE EXPANSION REQUIREMENTS

	CSFDR	ADDED FOR MONITORING
SIGNAL CONDITIONING		
DIGITAL	2	
ANALOG AC	9 HIGH LEVEL	8 HIGH LEVEL
ANALOG DC	12 HIGH LEVEL	6 HIGH LEVEL 20* VERY LOW LEVEL
DISCRETES	42	32 **
FREQUENCIES	4	
ACCELEROMETERS (VIB)		2
PROCESSING	40% UTILIZED USING 8085 AS A BASE	80% UTILIZED
DATA MEMORY SIZE		
BASIC CSFDR	130 KILOBITS	
ENGINE CONDITION		10 KILOBITS
STRUCTURAL MONITORING		600 KILOBITS
FLIGHT CONTROLS		NEGLIGIBLE
TOTAL	131 KILOBITS	
GRAND TOTAL		742 KILOBITS

* 14 IDENTIFIED BUT 6 ARE ADDED FOR MISCELLANEOUS PURPOSES
** 18 PRESENTLY IDENTIFIED BUT SHOULD PROVIDE ADDED CAPABILITY

E–9301

TABLE 74. IMPACT OF CIMBINING MAINTENANCE MONITORING CSFDR FUNCTIONS

	STANDARD CSFDR	SEPARATE MAINTENANCE MODULE	SUM OF MAINTENANCE MODULE AND CSFDR UNITS	COMBINED MAINTENANCE/ CSFDR UNIT
SIZE	177.5 IN^3	250 IN^3	427.5 IN^3	370 IN^3
WEIGHT	9.5 LBS	7.0 LBS	16.5 LBS	14.5 LBS
RELATIVE UNIT COST	1.0	0.7	1.7	1.5
RELIABILITY	8,300 HRS MTBF	12,000 HRS MTBF	4900 HRS MTBF	5700 HRS MTBF
MAINTAINABILITY	0.6 MMH/1000 FLIGHT HOURS	0.4 MMH/1000 FLIGHT HOURS	1.0 MMH/1000 FLIGHT HOURS	0.9 MMH/1000 FLIGHT HOURS

E-9302

4.0 GROUND SUPPORT EQUIPMENT AND GROUND BASED SOFTWARE

The requirements for Ground Support Equipment (GSE) were analyzed to the extent necessary to identify GSE costs. Two units were identified, the Ground Readout Unit (GRU) and the Field Maintenance Unit (FMU). The functions of these units and the feasibility of combining them into a single unit are discussed in the following sections. GRU designed specifically for supporting the maintenance functions defined in Sections 3.5 and 3.6 is also discussed. Finally, recommendations are made for ground based software utilizing either a dedicated minicomputer facility or an existing Air Force batch computer processing facility.

4.1 CSFDR GROUND READOUT UNIT (GRU)

The primary function of the GRU is to provide means for recording and transmitting data from the CSFDR airborne unit. GRU's would be made available at various sites where CSFDR equipped aircraft are based to provide rapid retrieval of CSFDR stored data. The GRU would interface to a functionally operating CSFDR via an adapter plug and wiring harness connected to the test connector provided on the CSFDR. A block diagram of the GRU is shown in Figure 33.

In event of mishaps, in which the CSFDR aircraft electronics interface is damaged or destroyed, the crash survivable module containing the solid state memory device would have to be mated to an operational CSFDR Electronics Unit at the depot or at the manufacturing facility.

The GRU will contain a cassette tape transport suitable for recording data contained in the CSFDR solid state memory device. Cassettes thus generated may be transferred to a centrally located Air Force batch computer facility (either physically or via modems interfacing to voice grade telephone lines). In any case, the cassettes become permanent records for mishap investigation files.

The GRU would be housed in a portable ruggedized carrying case designed to withstand the rigorous environments imposed by field usage. Two EIA RS232 interfaces are provided on the GRU for compatible operation with the CSFDR and modem.

When connected to the CSFDR via the PGU/CSFDR digital link (RS232 compatible), the CSFDR recognition discrete is activated which allows transfer of the solid state memory contents in eight (8) bit bytes. Data is transmitted via modem to the centralized computer facility in serial fashion.

The GRU continuously writes and reads data to and from a cassette cartridge. The RS232 ports can accommodate continuous data rates up to 9600 baud. The unit can be commanded, via front panel controls, to write, read, search for a particular record, edit a record, rewind and write an end-of-file gap. Data can be written on the tape in record lengths from one to 512 characters. Buffers are available in lengths of either 128 or 512 characters.

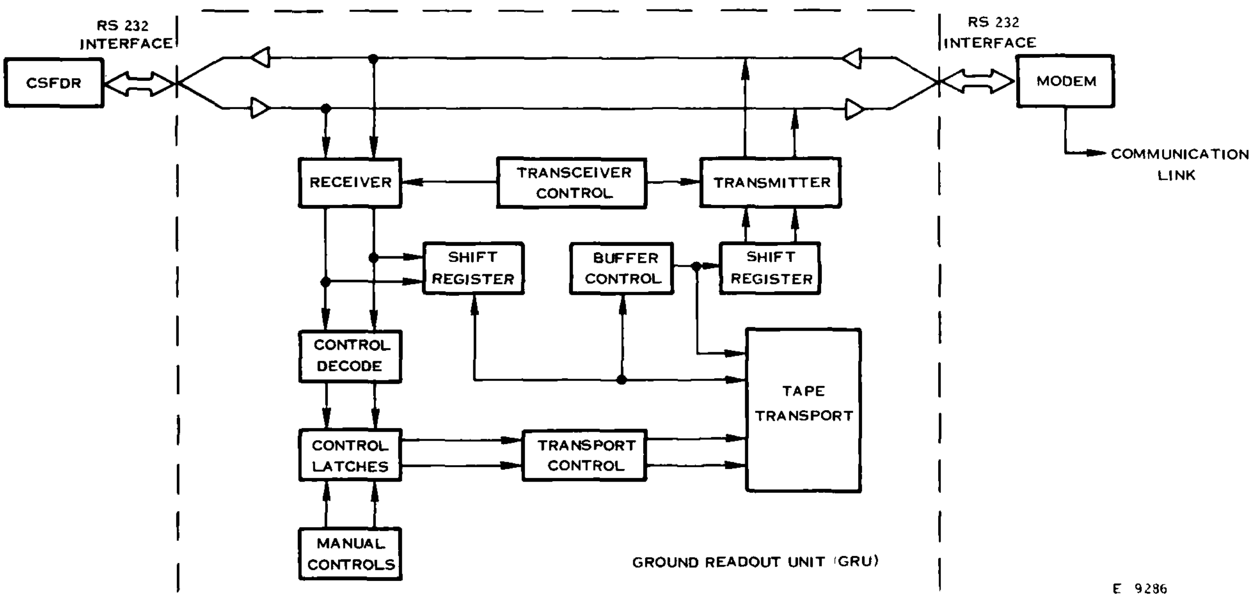


FIGURE 33. GRU TYPICAL BLOCK DIAGRAM

Several devices of this general description are available in industry as off the shelf hardware and are easily adaptable to the particular user requirements.

4.2 FIELD MAINTENANCE UNIT (FMU)

The primary function of the FMU is to provide capability to test the operational capabilities of the CSFDR at the intermediate level by providing means for fault isolation of replaceable modules in the CSFDR. A block diagram of the recommended FMU is shown in Figure 34.

The FMU proposed would be a portable, semi-automatic test unit which interfaces with the digital and analog I/O circuits of the CSFDR. Testing of the CSFDR is controlled via internal FMU test programs stored in programmable-read-only memory (PROM) which provides test diagnostics for determining CSFDR self-health and for fault isolation to a line replaceable module (LRU).

The FMU simulates on-aircraft discretes, AC and DC analog and frequency input signals in order to provide fault status of on-aircraft sensors. Lamp indicators and digital displays and test points on the FMU provide the status indications and monitor points of selected CSFDR parametric information.

The FMU will contain the necessary power supplies for internal circuit applications in addition to providing power throughput to the CSFDR. The FMU will also contain self-test-circuitry for verification of its own operational status.

The FMU will interface to the CSFDR via the EIA RS-232 interface port. Recognition of the FMU by the CSFDR is provided internal to the CSFDR in the test mode.

The various tests to be performed, as determined by FMU test program memory, would include the various tests listed below:

- Processor Instruction Test
- Processor Interrupt Tests
- RAM Test
- EPROM Verification Via Checksum
- Solid State Memory Storage Device Test
- DC Analog Output Static Test
- AC Analog Output Static Test
- Frequency Output Static Test
- Discrete Input Test

The various test points provided will allow check of CSFDR power supply voltages and selected critical signals internal to the CSFDR.

The tests will be formulated in such a manner to allow fault isolation of the CSFDR to a replaceable module level.

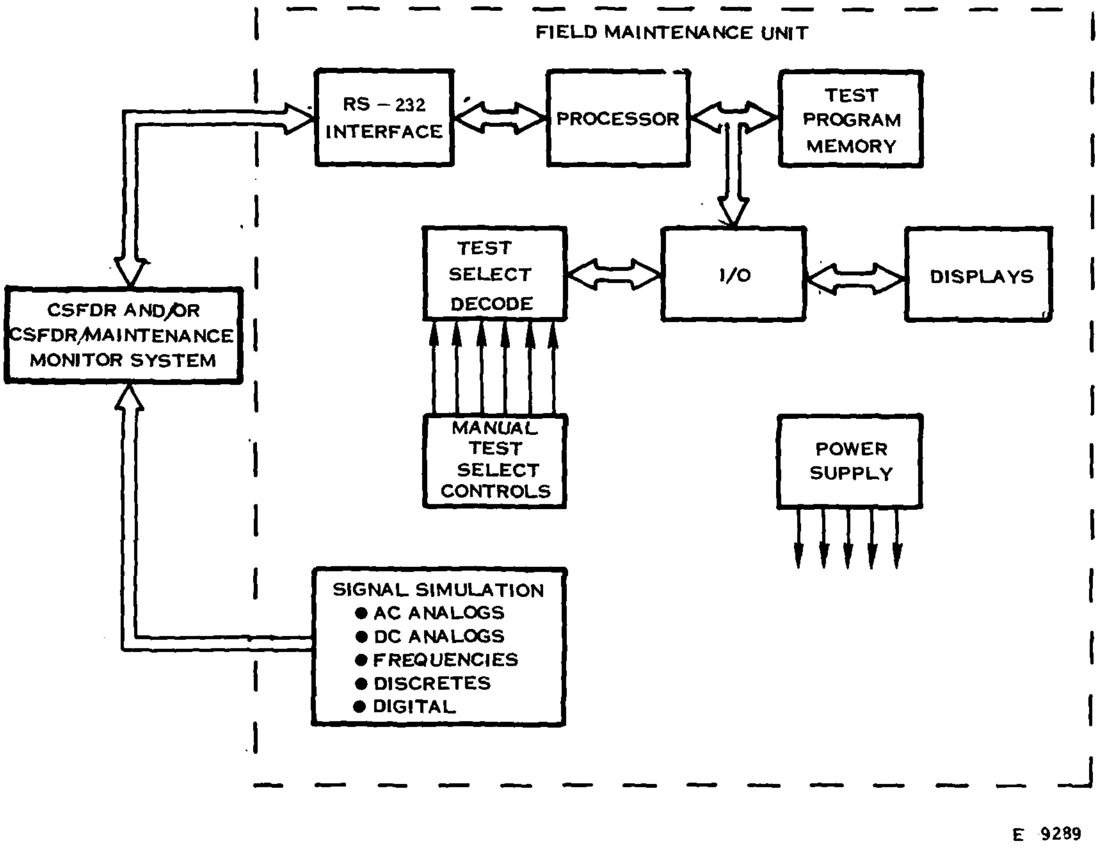


FIGURE 34. CSFDR FIELD MAINTENANCE UNIT BLOCK DIAGRAM

4.3 COMBINED GRU/FMU

The advantages and disadvantages of combining the functions of the GRU and FMU into a single unit were evaluated. The combined unit has the advantage of providing the dual capability of data retrieval and CSFDR fault isolation while reducing the inventory requirements for support hardware. There are, however, a number of disadvantages which outweigh these benefits. The GRU can be implemented with hardware available in the industry. The benefit of industry standard hardware is lost if this function is combined with that of the FMU. It is anticipated that utilization of the FMU capabilities will be low due to the high reliability of the CSFDR system and the high degree of BITE capability already available in the CSFDR. It is recommended, therefore, that the functions of the GRU and the FMU be implemented in separate units.

4.4 OVERHAUL, TEST AND DEPOT MAINTENANCE

The task of fault isolation, repair and test of the CSFDR to the component level was evaluated. This evaluation has resulted in a recommendation that the CSFDR line replaceable units (LRU's) be returned to the manufacturer for repair. This appears to be the most cost effective approach for several reasons. First, the technology used for the CSFDR results in a unit which requires no overhaul. Also, the CSFDR reliability factors indicate a minor cost factor associated with depot level repair to the component level. The associated cost factors are defined in Section 5.0.

4.5 GSE FOR CSFDR/MAINTENANCE RECORDER EXPANSION

The primary function of the CSFDR/Maintenance Recorder System GSE is to provide the flight line maintenance personnel the capability to immediately obtain selected information from the Maintenance Recorder System relative to engine condition and usage, g related structural integrity parametric information and logic analysis of all input data including the flight control signals for output via alpha numeric display and hard copy printouts. This information will provide the maintenance personnel with the necessary information to affect immediate and required maintenance activity in the field. The GSE unit would also be used for data extraction and cassette tape generation in support of mishap investigations in place of a separate GRU as described in Paragraph 4.1. A block diagram of the CSFDR/Maintenance Recorder GSE is shown in Figure 35.

The GSE will also allow maintenance personnel to generate dual tapes (one for field temporary files and one for transmittal to a central distribution center) which contains documentary data (i.e. aircraft and engine ID's, flight mission information, date, maintenance personnel ID, base ID, etc.) inputted via the keyboard control followed by all parametric information contained in the CSFDR/Maintenance Recorder system.

The keyboard control will also allow the maintenance personnel to select specific information required for immediate display on the alpha numeric display and to obtain hard copy printouts of this information for maintenance related actions at the flight line level.

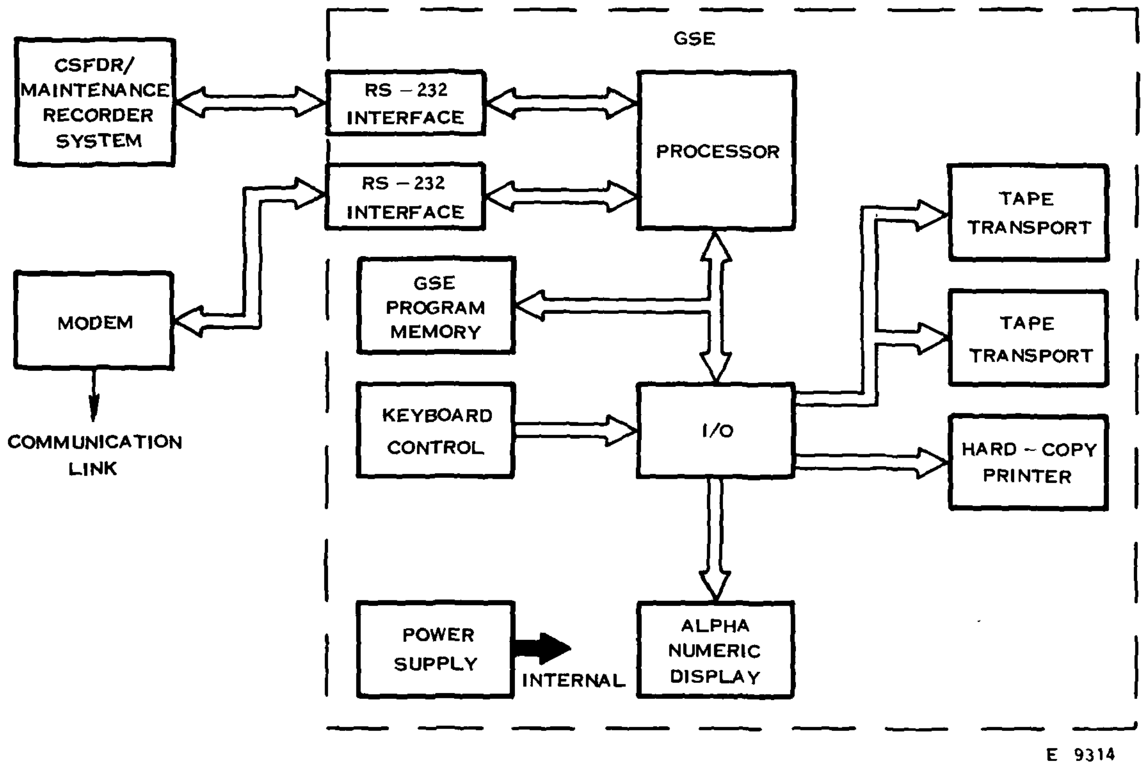


FIGURE 35. GSE BLOCK DIAGRAM FOR MAINTENANCE RECORDER

The GSE program memory may be tailored for the specific functions described above.

Of the two (2) tapes generated, one could be retained in a temporary file at the flight line while the second tape can be physically transferred and/or transferred via modem over voice grade telephone lines to a central distribution center for reproduction and further distribution to other agencies for further diagnostic/prognostic applications.

The GSE would be a semiautomatic, portable, ruggedized unit suitable for use in the field/flight line environments.

4.6 GROUND SOFTWARE FOR MISHAP INVESTIGATIONS

Ground data processing can be implemented by various methods. Data transfer from remote sites could also be provided by various methods. Data processing alternatives include the following:

(1) A stand-alone minicomputer based facility at a single fixed site. This could be located at either Tinker AFB or the Norton Air Force Base Safety Center and be an extension of an existing minicomputer facility.

(2) Use of existing Air Force batch process computer facilities.

In the above systems, data would be transferred by physically sending the cassette or transferral via telephone lines using RS232 compatible modems which are readily available. Control of the tape transcription via telephone lines would be by remote computer except the remote processor would read the tape only.

Central data processing is envisioned to provide such functions as plots of parameters versus time or groups of appropriately interrelated parameters versus time. Graphic plots are preferable; however, tabular data could be generated. A business computer compatible magnetic tape could be generated of either the raw data or decompressed data (i.e., gaps removed by filling in with data). These tables could be permanently used for more sophisticated fleet wide data analysis or used as inputs to a flight simulator.

The general arrangement of programs that could be developed and installed at an Air Force central ground computer facility is shown in the CSFDR Ground Software Outline of Figure 36.

Data is received from the CSFDR via cassette and or telephone transmission. The data could be stored in raw form at this point. At this juncture, some general purpose programs could be executed as shown to operate on the data and

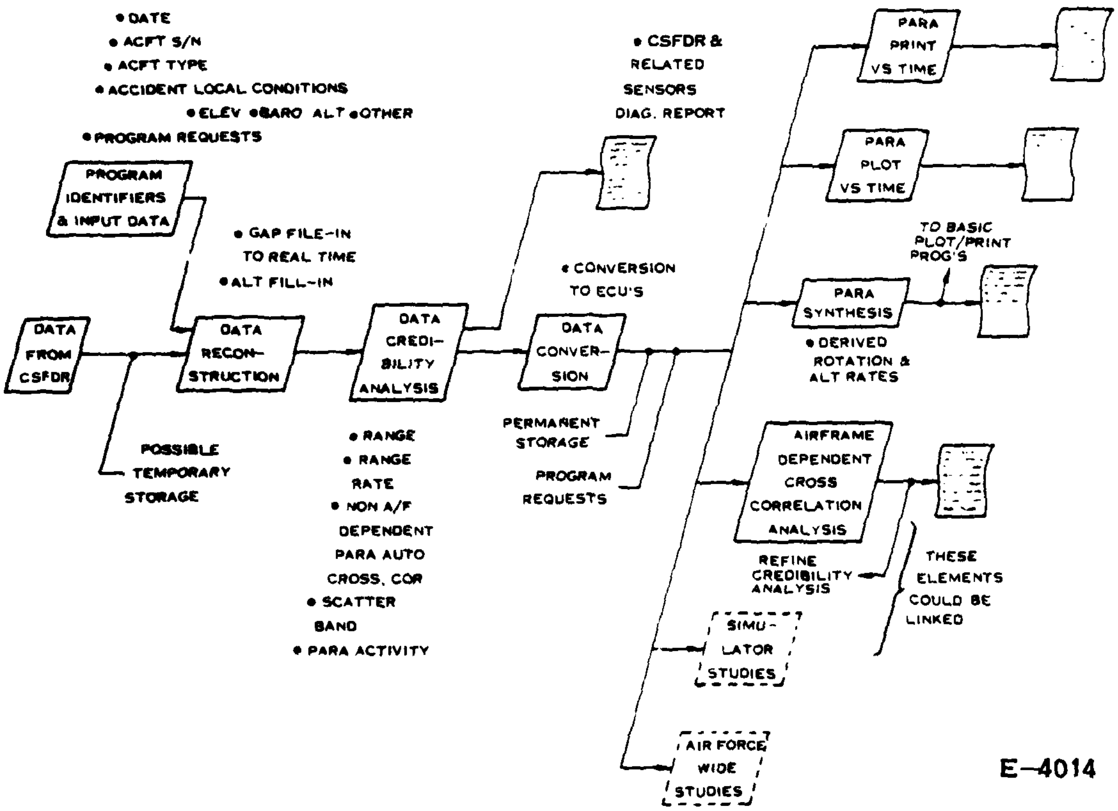


FIGURE 36. CSFDR GROUND SOFTWARE OUTLINE

bring it to the point of correction and conversion. The general purpose software program elements are as follows:

* Data Reconstruction - to real time. (Non-airframe dependent)

* Credibility Analysis - Out of range and range rate. Cross correlation such as attitude rate versus airspeed and pitch angle. Correlation of parameters such as vertical g's approximately equal to "one" with aircraft static if data is available. Parameter activity monitor and scatter band analysis can also be included. At this point a diagnostic report could be generated to list possible CSFDR or CSFDR related sensor malfunctions. (The credibility analysis program element would be somewhat airframe dependent, particularly with regard to range and range rate).

* Data Conversion - to engineering units with any suspect data taged. (This element is airframe dependent).

At this point, the corrected and converted data could be put on tape and permanently stored: Specific programs could now be called up to support the accident analysis. (The top four elements shown on the right of the referenced Figure 37 are not considered airframe dependent).

The specific program elements could include the following:

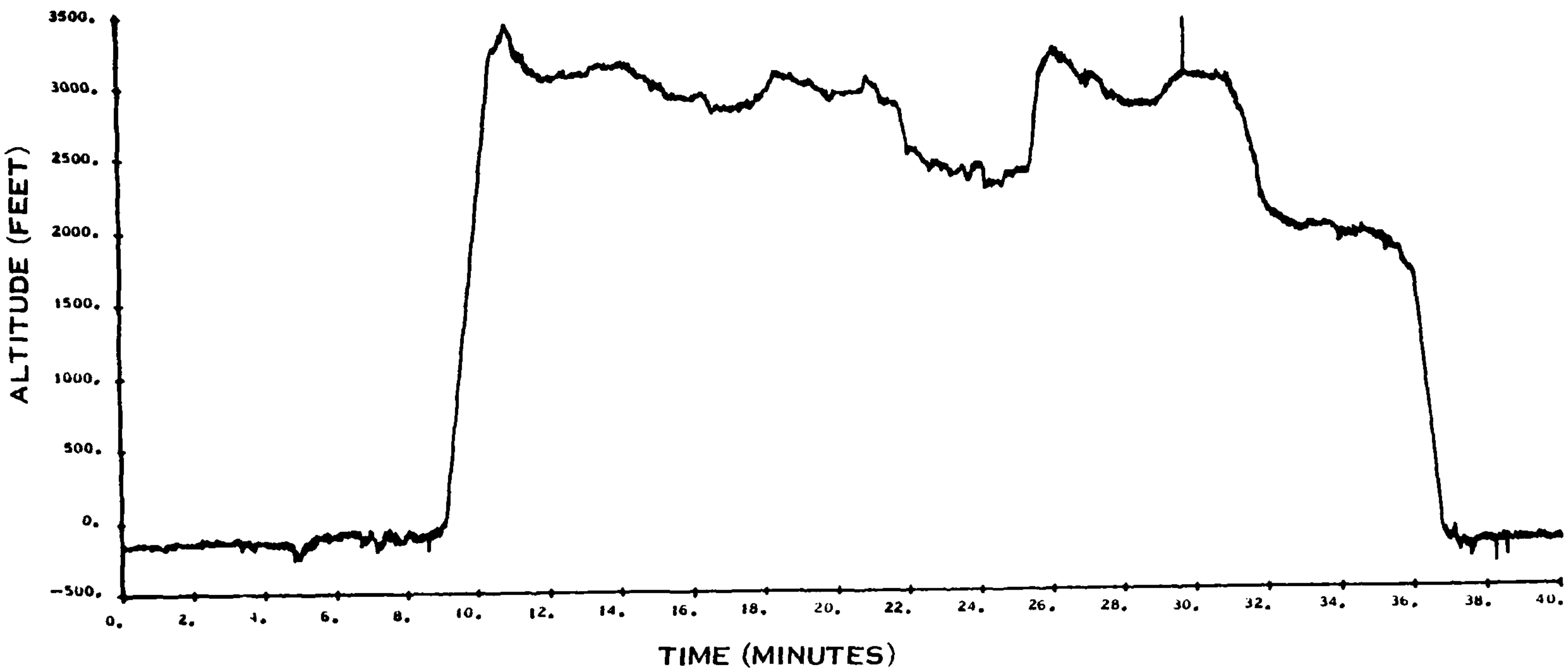
Parameter print versus time. This program would print out all the recorded parameter against time. See the following tabulation for example. Parameters would be listed in engineering units in the time sequence that they occured.

PARAMETER PRINTOUT VERSUS TIME

RELATIVE TIME FRAME (SEQ. #)	AIRSPEED (KN)	HDG (DEG)	ALT (FT)	PITCH (DEG)	ROLL (DEG)	ETC
7.81	110	99	7000	1.0	+5.0	
7.82	111	104	7005	1.0	+5.0	
7.83	114	108	7007	.5	0.0	

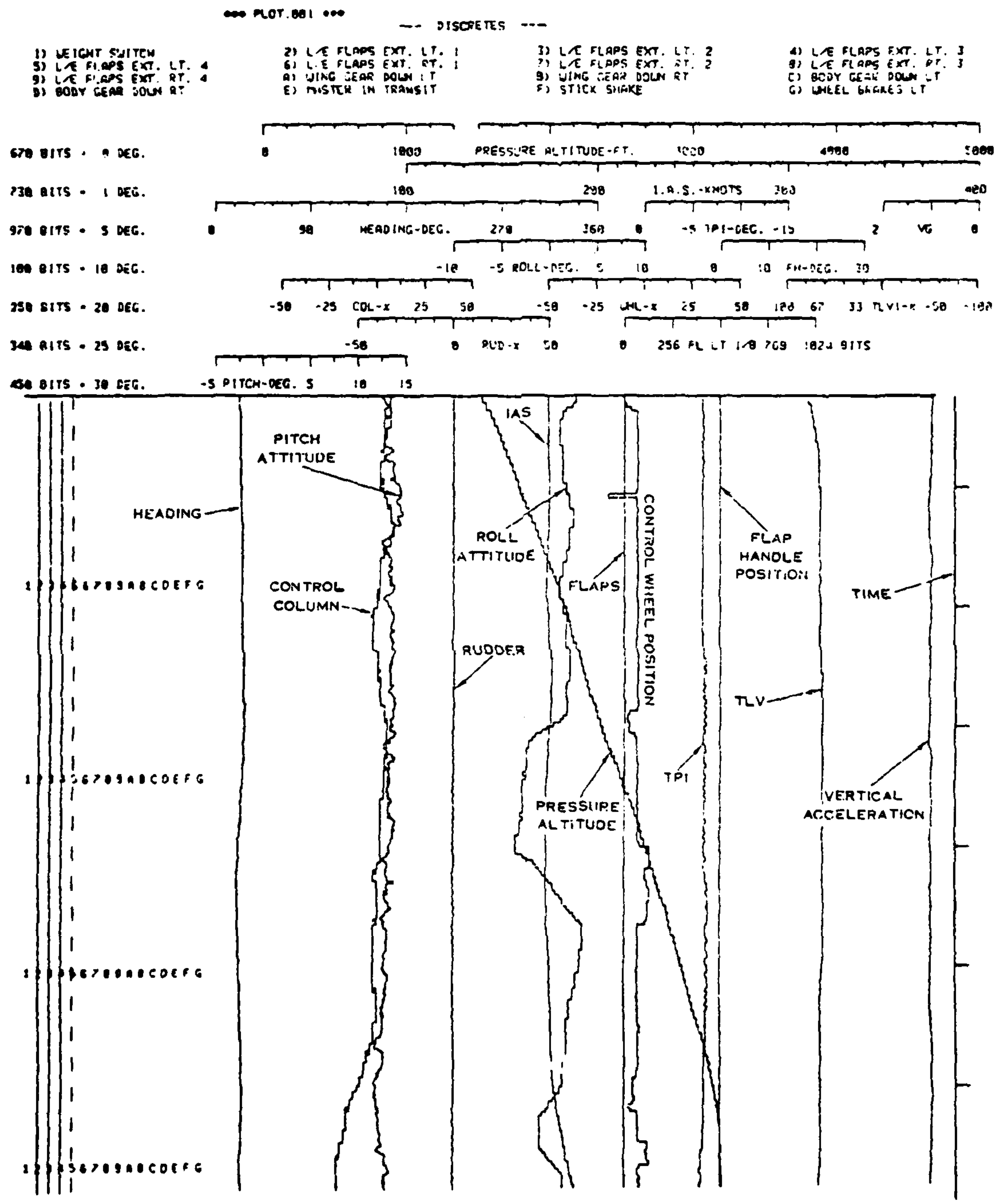
ETC.

Parameter plot versus time. This data presentation is shown in altitude plot as a single parameter plot (Reference Figure 37). Figure 38 shows a multiple parameter plot as currently developed for fixed-wing aircraft.



E—4002

FIGURE 37. ALTITUDE PLOT



E—3999

FIGURE 38. MULTIPLE PARAMETER PLOT

Parameter synthesis. Certain parameters can be derived from other parameters and provided as inputs to basic plot/print and other programs. For example, altitude rate may be extracted from fine pressure altitude data (and or radar altitude if available). Pitch, roll and yaw angular rates could be derived from pitch, roll and directional data. Continuous normal acceleration could be obtained from the pitch rate, airspeed product.

Airframe-dependent cross correlation analysis. This analysis could be used to further refine data credibility analysis prior to the onset of an incident and/or as an investigative technique in determining cause during the accident profile. For example, engine torques, speeds, and control input positions can be cross correlated for a particular airframe for data validity prior to an event and can be used to determine probable cause at the time of the event.

As an additional example, control input can be correlated with airframe responses such as vertical flight g's, and derived angular and linear rates. This data could be compared with flight simulator responses. It may be practical to perform this program element on the particular flight simulator itself or utilize CSFDR data as input conditions for comparative analysis in terms of aircraft response.

Once the data is permanently stored and a library is accumulated, further software can be generated to do Air Force aviation fleet wide studies.

A basic program would be designed with modular elements. Certain of the modules would be airframe dependent. Therefore, there is a one time cost for basic program preparation and an each time cost for each new airframe application. These costs are factored into the life cycle cost analysis as described in Section 5.0.

5.0 LIFE CYCLE COST ANALYSIS

This Life Cycle Cost (LCC) analysis presents the factors used by Hamilton Standard in developing the total estimated cost to the government associated with the acquisition and ownership of a Crash Survivable Flight Data Recording (CSFDR) System whose concept(s) are defined in this report. Detail dollar cost information will be provided to the Air Force under a separate cover since this information is considered proprietary to United Technologies.

The life cycle cost model(3) used for this analysis is operational on a United Technologies IBM 370 system and is currently used, and approved by the Army, for LCC analysis in support of the Black Hawk helicopter program.

The base analysis presented herein deals with the Basic CSFDR (Operational Configuration II) and traces the associated program costs from Production Design and Development, Demonstration and Evaluation, Production Fabrication and Test through Operation and Support costs over a twenty (20) year life. In addition, factors affecting production hardware costs and operating and support costs, were varied through a sensitivity analysis to illustrate affects on life cycle costs due to these factors. The sensitivity factors utilized are listed below:

* System Mean-Time-Between-Failure (MTBF)
* System Purchase Cost
* System Repair Cost
* Initial Spares Requirements
* Retrofit Kit Purchase Cost
* Retrofit Kit Depot Installation Cost
* Production Unit Material Cost
* Annual Discount Rate Variation

As a typical application example, the Fairchild Republic inputs were used in developing the baseline LCC estimates.

(3) Model based on: USAAVSCOM Technical Report 75-30 entitled "A Computer Model for Aircraft PIP and ECP Economic Analysis".

Delta affects to the baseline LCC were then determined for estimating the Expanded CSFDR (Operational Configuration II), including affects on Design and Development, Production and Test and Operation and Support Cost elements.

The delta LCC costs to the Basic CSFDR, which resulted from tri-service application and adding the Maintenance Monitoring functions, are also determined in this analysis.

LCC Baseline System Application

In order to perform the LCC analysis for the Operational Configuration II System, a CSFDR Program Plan was generated to reflect the various cost elements which would be involved in the analysis. The CSFDR Program Plan, reference Figure 39, is divided into six (6) phases with overlapping of phases to provide timely delivery of airborne hardware. As may be noted from the CSFDR Program Plan, no research and development phase is included since Configuration II is based on current proven technology. The schedule assumes a start date of 1 August 1981 for purposes of this analysis.

CSFDR Program Plan

The six (6) phases of the program plan are shown in Figure 39 and involve the following cost elements.

Phase I - Production Design

Phase I of the program plan involves all tasks (and thus all related non-recurring costs) necessary to establish detail system design requirements for both hardware and software, establish working agreements with the airframe manufacturer to coordinate joint efforts, generate the detail schematics, drawings, parts lists, software programs, test specifications and test hardware required in the fabrication, assembly and performance verification tests of CSFDR flight hardware. This hardware definition includes not only the CSFDR Electronics Unit (EU) and Survivable Memory Module (SMM) but also the additional aircraft sensors, aircraft wiring, aircraft braketry and mechanical installation requirements (initial ECP generation). In conjunction with the hardware definition, laboratory test equipment built and/or purchased to support engineering test and evaluation of limited production hardware is also included.

Design definition, including detail schematics, drawings, parts lists, software programs and test procedures for field support hardware (Field Maintenance Unit -FMU) are also accomplished in the Phase I effort The parallel efforts of flight and support hardware design allows early interfacing of requirements leading to effective fault isolation capabilities being incorporated in the CSFDR/FMU designs.

PHASE AND TASK	HSD ENG	HSD FIN CNTL	HSD OTHER	SUB-CONTRACT ENG	SUB-CONTRACT OTHER
PHASE I - PRODUCTION DESIGN					
1. PROCUREMENT SPEC NEGOTIATION	120	96			
2. SYSTEM DESIGN	780	20			
3. SUB-CONTRACT NEGOTIATIONS	160	80			
4. DETAIL DESIGN					
A) ELECTRICAL	4880	16	940		
B) MECHANICAL	5280	16	560		
C) SOFTWARE	3840	16			
5. DRAWING RELEASES	820	8			
6. TEST SPECIFICATIONS	510	16			
7. AIRFRAME DESIGN & DEVELOPMENT	240	32		7120	
8. SUPPORT EQUIPMENT DESIGN	5500	100	800		
9. GROUND SOFTWARE D&D	3310	110			
10. PROCUREMENT - MAT LS & SERVICES			33.9K		
PHASE II LIMITED PRODUCTION					
1. CSFDR FABRICATION & TEST	4300	90	6940		
2. CSFDR DELIVERIES					
3. GRU DEFINITION & PROCUREMENT	160	8	10K EACH		
4. FMU FABRICATION & TEST	208	60	1200		
5. FMU DELIVERIES					
6. RETROFIT KIT FAB & ASSY				80	400
7. CSFDR QUALIFICATION	2230	110	1180		
8. FMU QUALIFICATION	790	50	500		
9. PROCUREMENT - MAT LS & SERVICES			295K		
PHASE III TRAINING					
1. TRAINING MATERIAL PREPARATION	920	200	16.6K		
2. CSFDR TRAINING	160				
3. GRU & FMU TRAINING	160				
4. SYSTEM TRAINING	240				
5. GROUND SOFTWARE TRAINING	320				
PHASE IV - LIMITED IN SERVICE EVALUATION					
1. ON AIRCRAFT KIT INSTALLATION	40				960
2. CHECKOUT & CHECK FLIGHTS	720	40	270		
3. FLIGHT TESTS	1200	80	400		
4. FLIGHT TEST DATA ANALYSIS	2400	20			
PHASE V - PROD TOOLING & T/E					
1. PROD RIG DES., FAB, TEST					
A) PC BOARDS	1200		980		
B. MODULES	2200		2400		
C. END ITEM CSFDR	2600		1920		
2. MANUFACTURING SERVICES					
A. PROCESSES / TOOLING	100		250		
3. AIRFRAMER PRODUCTION TOOLING					2615
4. PROCUREMENT - MAT LS & SERVICES			94K		
PHASE VI PRODUCTION DELIVERIES					
1. RETROFIT KIT PREPARATION					
2. RETROFIT KIT INSTALLATION					
3. RETROFIT KIT HARDWARE					
4. FMU		30K EACH			
5. GRU PROCUREMENT		10K EACH			
CONTRACT DATA ITEMS					
PROGRAM PERFORMANCE PLAN	50	15			
SYSTEM DESIGN DOCUMENT	620	16			
ACCEPTANCE TEST PLAN CSFDR	450	16			
ACCEPTANCE TEST PLAN FMU	410	16			
QUAL TEST PLAN CSFDR	390	16			
QUAL TEST PLAN FMU	360	16			
GROUND SOFTWARE DOCUMENTATION	770	20			
OPERATIONS & MAINTENANCE MANUALS	1050	32			
QUAL TEST REPORT CSFDR	540	16			
QUAL TEST REPORT FMU	470	16			
FLIGHT TEST REPORT SUMMARY	380	16			
DESIGN DATA AS REQ'D	140	24			
DESIGN REVIEWS	460	20			
PROGRESS REPORTS MONTHLY	60	60			

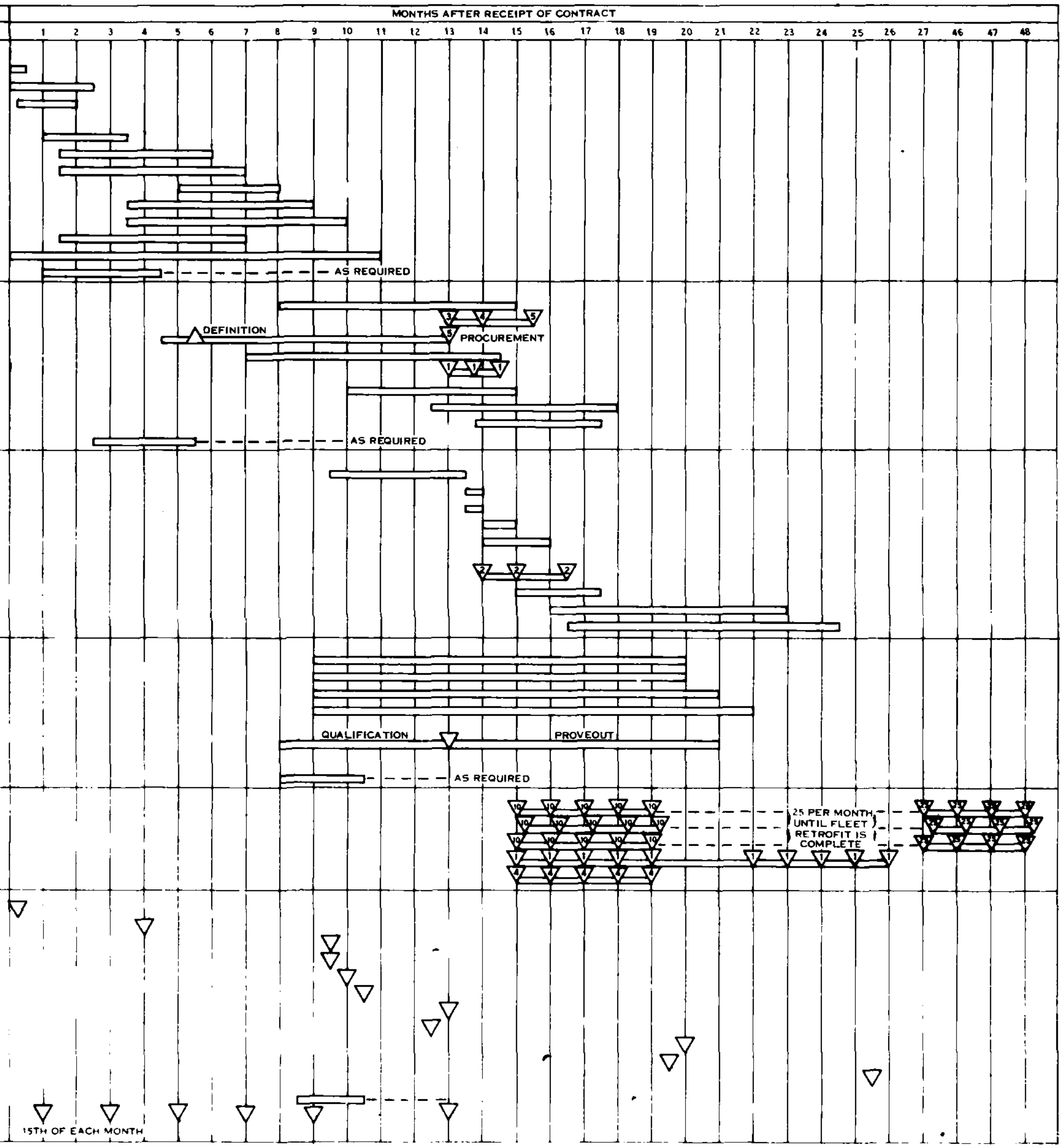


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FIGURE 39. CSFDR PROGRAM PLAN FOR LCC ANALYSIS

Ground software design and development is also included in the Phase I effort and involves develoment of the software package to allow the procurring activity to incorporate CSFDR data interpretation and evaluation capabilities on their batch processing computer facility.

All tasks include the materials and manpower required to accomplish the listed efforts.

Phase II - Limited Production

The Limited Production phase of the program involves all the non-recurring costs associated with the fabrication and test (including product acceptance and qualification) of production prototype hardware prior to committing to a full scale production program. The limited production of CSFDR hardware involves the buildup of twelve (12) prototype units for use in qualification and limited in-service evalution. This phase also serves as a pilot program for production planning to ease the transition to high volume production.

In addition, hardware required to support the CSFDR in the on-going program phases is procurred (in the case of the GRU) and/or fabricated and tested, including qualification (in the case of the FMU) during this phase of the program. The equipment provided will allow capabilities for maintaining the flight prototype CSFDR systems during the in-service evaluation and training phases of the program.

Phase III - Training

The training phase of the program includes all non-recurring costs associated with the preparation of training materials and the personnel required to instruct Air Force instructors and users in the operation and maintenance of the CSFDR system hardware, the ground support hardware (GRU and FMU) and the elements and usage of the ground software used to retrieve, analyze and process CSFDR data on Air Force batch computer processing facilities.

Phase IV - Limited In-Service Evaluation

This phase involves all non-recurring costs associated with flight testing and evaluation of information recorded during flight tests using the production prototypes delivered during Phase II of the program. The tests performed would serve to define any fine tuning requirements for the production CSFDR design prior to committing to high volume production.

Phase V - Production Tooling and Test Equipment

This phase of the program involves all non-recurring cost associated with the design and development of production rigs and tooling required for the support of a high volume production capability. This includes test rigs and fixtures for printed circuit board tests, module testing and end item production acceptance testing. The processes and tooling required to support a high volume production program will also be generated during this program phase.

Phase VI - Production Deliveries

The Phase VI element of the program plan involves all recurring costs associated with deliverable CSFDR system hardware and the operation and support efforts/costs to maintain the deliverable hardware throughout the life of the system. These cost factors include:

1. Hardware manufacturing costs related to deliverable CSFDR system hardware, both electrical and mechanical, procurement of component piece parts and fabrication.

2. Assembly and test costs involved with production hardware including quality control, packaging and transportation through to the contracting agency.

3. Initial spares involving initial provisioning of spare components as necessary for maintenance replacement purposes in end item CSFDR systems and for repair to support newly fielded systems to assure continued operation of the hardware until the pipeline supply system comes into routine operation.

4. Operations costs such as electrical power, computer consummables, operational personnel and facilities are considered minimal and are not factored into this LCC analysis due to the existance of such requirements now in affect in the Air Force.

5. Support includes all cost associated with the maintenance of the CSFDR and the CSFDR support hardware required to maintain the deliverable items in a serviceable condition throughout the life of the hardware. These costs involve procurring activity cost at the line and intermediate level of maintenance and contractor services at the depot level of maintenance.

6. Replenishment spares involve all costs associated with flight hardware spares required to resupply the system stock requirements due to discarding or scrapping of items during the maintenance process.

NOTE: The costs associated with deliverable ground support hardware (GRU and FMU) are included in this phase; however, these cost elements form a part of the non-recurring cost factors for the LCC analysis.

5.1 LIFE CYCLE COST ESTIMATES

The following presents a detailed breakdown of all factors used in developing the specific life cycle costs associated with the three (3) system configuration concepts discussed in the report.

LCC Baseline System Application

The baseline LCC includes all cost factors defined in Section 5.0 as it applies to the Basic CSFDR (Operational Configuration II). The LCC develops the cost factors using inputs from Fairchild Republic, on the A10 as a typical installation on one of the three airframes studied.

The baseline LCC assumes a one box, single design configuration which can be installed in any of three (3) different aircraft, i.e. A10, F15, F16).

Baseline Non-Recurring Investment Costs

The non-recurring investment cost factors involve all elements of the Phase I through Phase V efforts depicted in Figure 39, CSFDR Program Plan plus the costs associated with ground support hardware deliveries included as a part of Phase VI and those costs associated with CDRL items. Figure 40, provides a monthly cost profile presented in percentages of the total non-recurring investment costs associated with the entire effort.

These non-recurring investment costs were based on the development of a high volume production line capability which would allow equipping the entire expected fleet of A10 aircraft on a field retrofit basis. The fleet of A10 aircraft considered totaled 739 (less attrited aircraft to date) with a retrofit completion goal set in early 1985.

The Phase I Production Design cost element thus involves all non-recurring effort to design the CSFDR including generation of the schematics, drawings, parts lists and software definitions necessary to define the Basic CSFDR system for productionization. In conjunction with this effort, peculiar laboratory test hardware will be defined and fabricated to support the initial test and proveout of prototype hardware including generation of preliminary test procedures for modules and the end item CSFDR. This phase will also include the generation, by the airframe manufacturer (Fairchild Republic) of the necessary documentation, including schematics, drawings and parts list to define the aircraft wiring and installation definitions (initial ECP generation) for incorporating the Basic CSFDR and additional sensors on the A10 aircraft. The above engineering efforts also include basic studies involving detailed thermal and mechanical stress analyses, detailed studies related to aircraft weight and balance effects, etc.

The generation of design details for support equipment (i.e. the Field Maintenance Unit - FMU) is also accomplished during this phase in order to provide for timely fabrication of hardware for maintenance of the CSFDR system during the flight evaluation phase of the program.

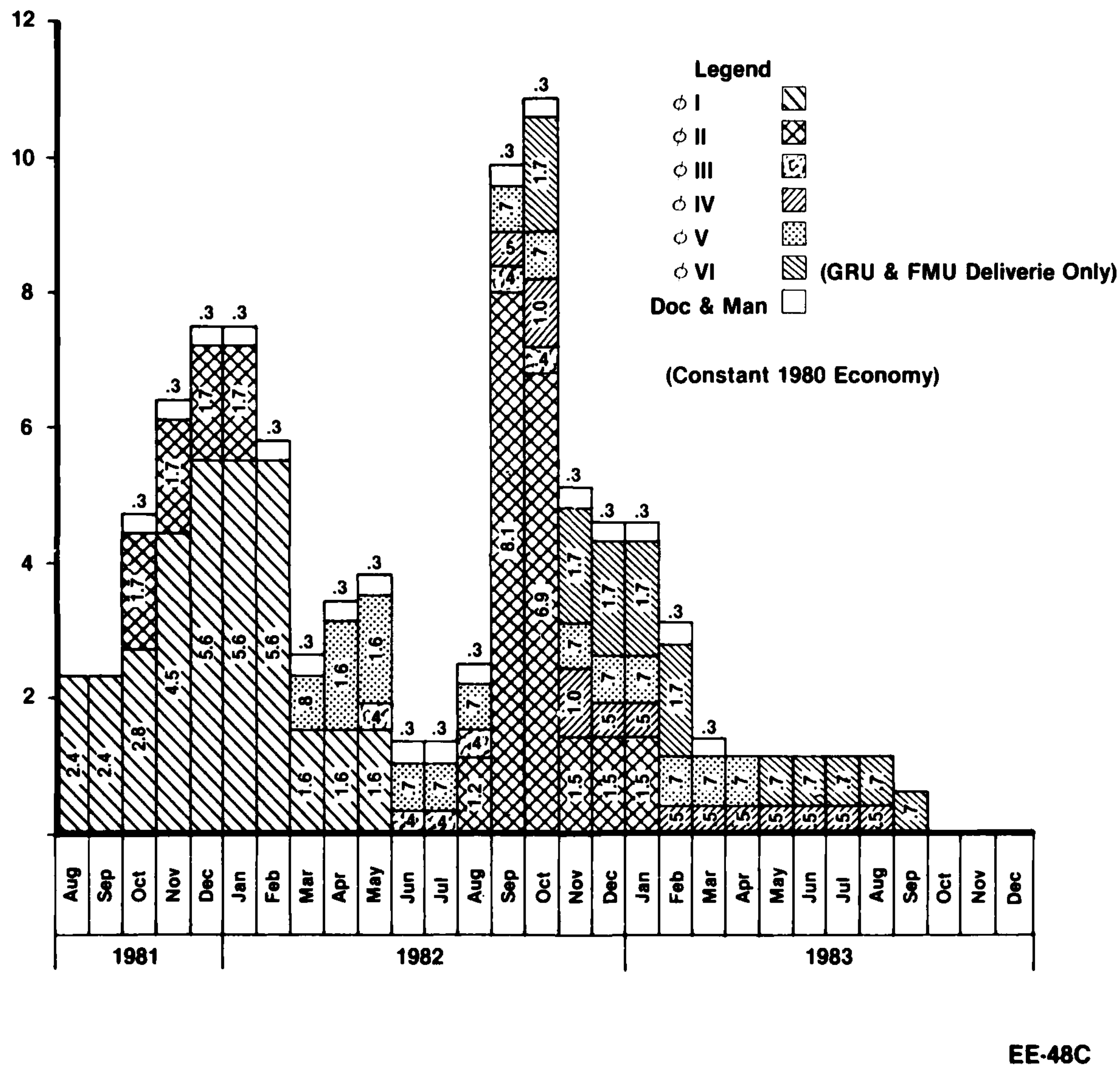

FIGURE 40 CSFDR NON—RECURRING INVESTMENT COST SUMMARY

Ground software design and development to support the evaluation phase of the program is also initiated during this phase.

The contracting agency will be kept abreast of program developments through periodic letter Progress reports and detailed design reviews to assure a smooth transition of technology exchange and allow maximum cooperation in implementing the CSFDR in the operational aircraft.

All materials and services required for the above cost elements are included in this phase of the program.

The Phase II Limited Production program involves all the non-recurring costs associated with the fabrication and tests (including environmental qualification) of production prototype hardware prior to commiting to a full scale production program. The limited production of CSFDR systems involves the buildup of twelve (12) prototype units for use in qualification testing and limited in-service evaluation tests on board selected operational aircraft. This phase also would serve as a pilot program for production planning to ease the transition to high volume output of system hardware.

The preparation of retrofit kits for A10 aircraft is a part of this phase and would include the Basic CSFDR, the additional sensors required on the A10 aircraft including sensors for Rudder Position, Elevator Position and Aileron Position, Left Power Lever Angle (in only every other A10 aircraft) and Right Power Lever Angle, the necessary bracketry required to install the CSFDR and additional sensors and the wiring harnesses to interface the CSFDR to existing and the additional aircraft sensors.

In order to support the equipment in operation, three (3) FMU's are included during this phase, one (1) FMU would be subjected to environmental qualification testing to demonstrate satisfactory operational capabilities throughout its intended usage.

Commercially available Ground Readout Units (GRU) would be defined and procurred during this phase of the program to support flight test data retrieval from the CSFDR for evaluation purposes and assistance in setting up the Air Force investigation personnels batch processing computer facilities. A total of five (5) GRU's have been included for procurement during this phase.

All materials and services required to accomplish the above efforts are included in this phase of the program.

The Phase III Training cost element involves all non-recurring materials and manpower necessary to familiarize and train Air Force instructors and maintenance personnel in the operation and utilization of the CSFDR, GRU and MRU hardware both in operation and maintenance functions. This phase also includes training Air Force personnel in the operation of the ground software programs used in retrieval and analysis of compressed data stored in the CSFDR survivable memory storage device. This cost element does not include Air Force facilities cost utilized in the training program which are primarily associated with the Air Force batch computer processing facility.

A limited In-Service Evaluation program defined in Phase IV involves the non-recurring costs associated with CSFDR systems installation, providing contractor support during flight testing and flight test data evaluation support in conjunction with Air Force personnel on government batch computer processing facilities. These costs do not reflect aircraft flight expenses but assumes the evaluation program occurs during normal operations involving the aircraft equipped with CSFDR prototype systems.

Phase V of the program involves all non-recurring cost associated with the design and development of production rigs and tooling required to support a high volume production capability for both hardware fabrication and test plus wiring and installation fixturing for on aircraft incorporation.

The test rigs include fixtures for printed circuit board tests, module testing and end item CSFDR production accpetance tests. The process and tooling required to support a high volume production program will also be generated during this program phase.

Phase VI includes the non-recurring costs associated with low level fabrication and test of ground support hardware such as the Field Maintenance Unit (FMU). Ten (10) FMU's were selected for dispersion to various major bases where A10 aircraft will be located in order to support maintenance, (i.e. trouble-shooting, repair and operational tests) of the CSFDR system throughout the system life.

A quantity of ten (10) Ground Readout Units (GRU's), which are used primarily to extract data from CSFDR's following an aircraft mishap, has been selected for the LCC analysis. Further study will define the exact number required for Air Force personnel usage.

The preliminary Contract Data Requirements List (CDRL) depicted in Figure 39, indicates the cost factors associated with expected documentation required by the Air Force during the course of the CSFDR program.

Baseline Recurring Costs

The recurring cost elements of the analysis include the total quantity of CSFDR systems required to equip the entire fleet of Air Force planned A10 procurement of 739 aircraft less attrition, initial spares required to sustain the newly fielded system operational capabilities and the replenishment spares required to maintain the flight hardware over the full life of the system. The total life cycle of the system for this analysis is twenty (20) years.

The factors involved with each category of recurring costs defined above are as follows:

Original Hardware Procurement and Installation

Original hardware procurement is determined by the total number of aircraft planned for the fleet modified by the number of attrited aircraft expected during the CSFDR system procurement and installation cycle using an aircraft

attrition factor of thirty (30) per one million fleet flying hours. Of the original 739 planned aircraft, twenty-two (22) have already been lost and thus only 717 are used in the analysis from the August 1981 start date through system life.

Fleet flying hours are determined using a factor of thirty-one (31) flight hours per aircraft per month for the entire fleet which is in operation at the start of the analysis and those aircraft which are scheduled to become operational during the CSFDR system procurement cycle. Fleet flying hours accumulated prior to August 1981 are disregarded in the analysis. To simplify the analysis, all 717 aircraft were assumed operational at the start of the analysis and thus equipping would be completely covered by field retrofit.

The cost elements involved in retrofit kit hardware and on-aircraft installation include one CSFDR Electronics Unit with an integral crash survivable memory unit. The derivaion of CSFDR cost included the materials cost both electrical and mechanical, based on fabrication in lot quantities of two hundred (200). This cost element is treated as GFE in this LCC analysis.

The various cost elements involved in the manufacture, assembly and test of the CSFDR were based on a compilation of the total number of operations involved in the CSFDR manufacturing cycle and then applying time study information to determine the total man hours required for the manufacturing assembly and test cycles. This method is standard practice in all Hamilton Standard operations. Piece part material cost are based on quantity buys of the material required and has been estimated based on current industry pricing. This information, covering industry pricing for the estimated parts complement of the CSFDR, are kept on computerized file at Hamilton Standard and continually updated to reflect current price structures.

Other items required in the retrofit kit, based on the A10 aircraft, included three (3) control position sensors (Rudder, Elevator and Aileron) plus Left PLA sensors for every other A10 aircraft and a right PLA sensor for every aircraft. Fairchild provided definitions on suitable sensors for these functions along with quantity prices for each.

Miscellaneous materials required for A10 installation of CSFDR and new sensor requirements included bracketry and wiring harnesses and their associated connector interfaces. Preliminary definitions on all required hardware for the wiring and installation plus their associated costs were provided by Fairchild.

Labor estimates were also provided by Fairchild for kit materials preparation and assembly based on the total quantity of aircraft involved in the study. A time factor was developed for the kit production for the first 100 aircraft and then for the next block of aircraft from 101 through 616 based on similar operations involved with similar aircraft hardware using labor estimate procedures presently employed with the A10 aircraft. In order to simplify the LCC analysis, since the computerized LCC model used is unable to compensate for

the sloped variations involved in kit production, an average time based on the entire number of aircraft kits involved was used and represented a fixed kit production time of 15.7 hours per retrofit kit.

In order to provide insight into the affects of varying cost elements involved with kit hardware, a sensitivity analysis was performed on the original purchase cost by varying the baseline cost over a range of approximately - 13% to +21% in increments of 3%.

The remaining cost element in equipping the A10 with CSFDR systems involved the installation of retrofit kits in the field. Again, Fairchild provided estimates based on the number of operations involved in the installation process and applying learning curves over the entire fleet installation program. For the purposes of the analyses, it was assumed that installation of CSFDR systems occurred in the same month in which they were delivered.

Again, an average installation time was selected for the analysis. The value selected was forty hours (40) per aircraft installation. Subsequent discussions with Fairchild indicated this to be a fairly conservative figure and a more realistic figure would be more like twenty (20) hours per aircraft. To provide an insight into the affects of varying installation times, a sensitivity anlaysis covering installation times of from ten (10) to forty-five (45) hours per aircraft in five (5) hour increments was performed for the analysis.

Initial Spares

The initial spares cost element selected for the analysis was 5%. This factor allows filling of the pipeline to sustain the newly fielded hardware in an operational readiness condition until such time that replenishment spares for failed items become available and/or failed items are repaired.

The initial spares cost include all hardware and associated preparation labor as defined for the retrofit kits described in the preceeding paragraphs.

A sensitivity factor relating to the initial spares was included in the analysis covering a range of 0 to 11% spares in 1% increments.

Replenishment Spares

This element deals with the repair or replacement costs associated with failed items at both the intermediate and depot level of maintenance. This cost factor occurs only when an individual part of the CSFDR system fails. The failure rates specified for the CSFDR system is 7120 hours MTBF based on current technology. In order to determine affects on costs for varying MTBF factors, a sensitivity analysis was performed using a range of 6000 to 11500 MTBF in increments of 500 hours. For purposes of the analysis, the MTBF and MTBR are used interchangeably.

Other cost factors used in the determination of intermediate level repair costs included the repair and replacement time factors defined below:

1. Man hours to replace a failed item in the field or depot of one (1) hour including test setup, fault isolation, replacement of failed module and verification of repair.

2. Repair to the component level would appear to be most cost effective if the depot level of repair is performed by the equipment manufacturer and, for this reason, no depot level test equipment costs have been included in the analysis. Total cost involved over the life of the system including repair of failed items to the component level is only slightly higher than would be the cost involved in the purchase of depot level test equipment which would be available at the manufacturer's facility.

The repair factors used for the analysis at depot level include a 3.62 hour average repair time per failure and a nominal $500 in materials per repair. These factors were arrived at based on a similar system on board a military aircraft (i.e. the flight control computer on the Army Black Hawk helicopter).

A scrap factor of 6% for the CSFDR system was used in the analysis and would amount to approximately six (6) systems over the life of the hardware.

Added Cost Factors Involving the F15 and F16 Aircraft

As was previously stated, the costs arrived at in the LCC Baseline System application involve application of a CSFDR to one aircraft type. Systems equipping all three (3) aircraft (A10, F15 and F16) would entail added costs in the following areas:

Added Non-Recurring Costs

Assuming that a similar time frame for equipping the F15 and F16 aircraft as that shown in Figure 39 CSFDR Program Plan, additional costs would include Phase I Production Design efforts by both McDonnel Douglas and General Dynamics in generating wiring and installation documentation required in the F15 and F16 respectively. The F15 aircraft would require addition of four (4) sensors not presently engineered into the aircraft including Left and Right PLA sensors and Left and Right Afterburner Nozzle Position sensors. This effort is assumed comparable to the Fairchild effort. The F16 on the other hand would not require any additional sensor design installation effort but would only require definition for wiring and installation of the CSFDR. The GD effort in this area is therefore assumed to be approximately 50% of the Fairchild and McDonnel Douglas effort.

The coordination efforts of Hamilton Standard in interfacing with three (3) airframe manufacturers to accomplish the above efforts is therefore tripled in both the Phase I; Task 3 and 7 cost elements.

The cost element involving Ground Software Design and Development is a second area in which differences exist between the three (3) airframes. These subtle differences are not expected to impact the basic software elements to a great extent, however, an additional 20% cost factor would be added in the Phase I, Task 7 effort to include these differences.

No impact on the Phase II effort is expected since the hardware is designed to interface with any of the three (3) aircraft and may, at Air Force discretion, undergo Limited In-Flight Evaluation tests on one, two or a combination of all three (3) aircraft. However, the estimates provided cover for a maximum of six (6) aircraft equipped with CSFDR systems.

The Phase III and Phase IV cost elements are somewhat affected by the resolution of ground software differences in training and in periodic evaluation data analysis. A delta of 20% would be added on each phase for this effort.

The Phase VI cost element is expected to increase by a factor of approximately two (2) due to the necessity of providing a higher degree of production test capability to triple the rate of hardware deliveries in the time frame specified.

Phase VI Production non-recurring deliveries involving all three (3) aircraft relate to the additional required GRU's and FMU's to support data retrieval efforts and maintenance efforts respectively at the separate bases where F15 and F16 aircraft reside. A factor of three (3) times the original quantity (and thus cost) can be assumed worse case. Some operational bases may have one or more of the considered aircraft types resulting in reduced GSE requirements.

Taking all factors above into account, the non-recurring effort to satisfy the needs of A10, F15 and F16 would increase by approximately 50%. Conversely, the non-recurring cost assignable to each airframe would be 50% of the number estimated for the A10 alone assuming an equal distribution.

Conclusions

Major savings could be realized by the government in a combined program of equipping A10, F15 and F16 aircraft with a standardized CSFDR system such as concepted herein. The savings in non-recurring development costs alone would result in spreading development costs over the three airframe programs resulting in 150% of the total non-recurring costs being shared by all three programs.

Recurring costs savings resulting from shared operating and support cost elements are another potential area of significant savings. However, the determination of these cost factors are complex and require a detailed analysis of the interlocking logistics and support systems. This is considered to be beyond the scope of this preliminary analysis.

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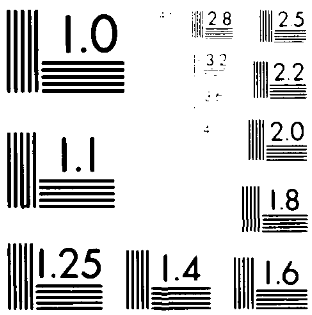

MICROCOPY RESOLUTION TEST CHART

LCC SYSTEM TRADEOFF AND EXPANSION EFFECTS

The LCC analysis with respect to the Alternate Configuration I System factors in new technology which will improve the reliability factor on the CSFDR from 8300 hours MTBF (CSFDR unit only) to 9200 hours MTBF. This improves CSFDR System reliability from 7120 hours MTBF to 7700 hours MTBF. In addition, the delta in CSFDR cost will show an improvement of approximately 10% as further component integration and cost economies in state of the art microelectronics is realized. This will reflect an overall installed system cost improvement of approximately 6%.

Impact on the non-recurring cost elements is expected to be minimal. For purposes of this tradeoff analysis it is assumed that a Configuration I development program schedule slips to the right in time and that the improvements in technology are available at little or no added cost.

The sensitivity analysis conducted for the baseline system LCC analysis allows estimation of the principle savings resulting from the above improvements as it relates to the total recurring investment cost and the operating and support costs.

Table 75 provides an estimate of the total percentage delta increse to the LCC estimates which results in going from the Configuration II to the Configuration I system concept.

TABLE 75. CONFIGURATION I AND CONFIGURATION II COST TRADEOFFS

COST ELEMENT	DELTA INCREASE (DECREASE)
Design & Development	+2%
* Reliability Delta	-0.1% of Recurring Costs
* Unit Cost Delta	-0.4% of Recurring Costs
Total Delta	Negligible

* Using the LCC sensitivity analysis results on an individual basis.

From the above analysis total delta improvement in relaibility factors plus reduction in unit cost using 1985 technology provides no significant cost benefit in constant dollars.

TRI-SERVICE STANDARDIZATION EFFECTS ON LCC

The primary impact of tri-service standardization on the LCC is in the area of non-recurring development cost factors. Assuming that the tri-services agree on a common specification for the basic flight data recording system, the design efforts could then be shared equally and thus reduce non-recurring by

an appropriate shared factor. Since the Air Force requirements are the most comprehensive, the baseline system concepted for the Air Force represents the most comprehensive design effort. The actual split in costs would depend on the number of services participating and the discounted costs unique to each services requirements.

Cost factors which would add delta increases to the non-recurring efforts such as each airframe manufacturer design and development plus peculiar ground software development applicable to the particular service using the system capabilities represents approximately 15% of the total non-recurring cost element.

It may be assumed that the fly away costs associated with a higher rate production line to supply the tri-services with a significant number of CSFDR systems would reduce the cost per unit as a result of higher piece part purchases by the manufacturer, however, this cost element may be more a function of lot size purchases and in any case does not appear to be significant as a potential cost reduction factor. Some operation and support cost savings may also be realized.

MAINTENANCE RECORDER EXPANSION IMPACT ON CONFIGURATION I CSFDR

The cost impacts addressed here on the expansion of the Configuration I CSFDR include only those affects to the basic recorder unit and do not include costs related to additional sensors required on the airframe and engines itself and the associated costs related to development installation of added sensors. Costs due to mounting sensors on engine or airframe would be highly variable and contain elements from the airframer and engine manufacturer.

The basic system design and development effort would be impacted by the addition of sensor interface complexity and interactive requirements of the data bus interfacing between the basic CSFDR and the Maintenance Monitoring system. The additional design effort including design, layout drafting and software design and development would increase this cost effort by a factor of approximately 40%. Ground Software design and development costs would be highly variable depending on the airframe and engines and the chosen techniques and cannot be estimated at this time.

The recurring fly-away cost is estimated to increase 100% over the Basic CSFDR System as a result of the increased purchase cost of the hardware and the installation cost of added boxes and sensors. The following tabulations illustrate the delta to the baseline LCC due only to those factors which can be addressed at this time. Reference Table 76. Operation and support costs would also increase substantially.

One Versus Two Box Baseline CSFDR Cost Factors

The trade off study described in Section 2.7 concluded that a single unit CSFDR centrally located is a more cost effective approach than a two unit concept with the survivable memory module in the tail. The following analysis

addresses this conclusion in more detail based on the results of the LCC and its sensitivity analysis and the results of the cost benefit study. Reference Table 77.

The following principle trade off factors are estimated:

TABLE 76. TOTAL LCC DELTA

COST ELEMENT	DELTA
Design and Development of airborne electronics	
CSFDR/Maintenance Unit D&D	40% Increase
Ground Software D&D	50% Increase
Reliability - Airborne Electronics	
(70% decrease in MTBF)	1.5% Increase
CSFDR/Maintenance Monitor Electronics Cost	70% Increase

TABLE 77. TRADEOFF COST FACTORS

TWO UNIT SYSTEM		SINGLE BOX SYSTEM
Reliability	3,600 Hours MTBF	7,120 Hours MTBF
Fly-Away Cost	1.4	1

LCC COST DELTAS

(From Sensitivity Analysis)

Reliability	+1.5%
Fly-Away Cost	+24%
Sub Total	25.5%
	or 2.8 million dollars

Estimated

Non-recurring 0.8 million dollars

Grand Total 3.6 million dollars

The benefit analysis in Section 5.2 concludes that for a single box CSFDR with a survival probability of 90% for Class A mishaps that 3.0 A10 aircraft would be saved over the 20 year analysis period.

If the survival rate is incrased to 95% for a two unit CSFDR with a tail mounted CSMM, then the number of aircraft saved increases to:

$$\frac{.95}{.90} \times 3.0 = 3.17 \text{ aircraft saves or a } 0.17 \text{ increase in saves.}$$

Taking the current cost of an A10 at 6.3 million dollars the above dollars saved is 0.17 X 6.3 = 1.07 million in current dollars.

This compares to an LCC increase of 3.6 million dollars.

From the foregoing analysis it can be concluded that the increased investment cost of the two box system is not justified.

5.2 COST BENEFIT ANALYSIS

Prevention of mishaps and improved flight safety are the primary benefits derived from using the CSFDR. The CSFDR can provide Air Force mishap investigators with comprehensive pre-mishap flight data. The addition of this parametric data in the hands of experienced and trained accident investigators will increase the speed and accuracy of mishap cause determination.

The objectives of this entire study is aimed at the reduction of aircraft attrition resulting in:

* Preserving vital personnel resources

* Improved mission effectiveness

* Reduced cost (i.e. reduction in aircraft destroyed, aircrew training plus replacement and repair of damaged aircraft)

The August, 1979 AFISC Statement Of Need (SON) points out the problems of operating without FDR's on attack/fighter/trainer aircraft.

"Current aircraft ... are deficient in their capability to record vital flight performance parametric information ... for use in post mishap investigations".

"Lack of data masks mishap causes and negates the purpose of mishap investigation ... prevention of future mishaps for like causes".

"Since we are faced with ... increasing training requirements, budget limitations, shrinking personnel resources and experience levels and highly complex weapon systems which do not permit easy identification of malfunction causes, ... imperative that we make every effort to protect our weapon system assets by minimizing mishap losses.

A crash-survivable FDR is a tool which will help meet this need".

"1. Mission: The purpose of mishap investigation ... identify causes ... take corrective action ... prevent future mishaps for those causes.

"3. Operational Deficiency:
a. Many findings of mishap investigation boards are based on probable sequence of events due to lack of concrete evidence".

"3. Assessment:
h. This lack of positive identification of mishap cause means no lessening of the risk of repeated mishaps for like cause and renders impossible the taking of positive corrective actions".

"5. Impact of staying with present capability:
Lack of (FDR's) will continue unsatisfactory ... investigative methodology ... increase the risk factor for repetitive mishap for like causes".

Mishap Data

In the period from 1975 to 1980, the USAF incurred 543 Class A mishaps and 660 fatalities according to AFISC records. Attack/fighter/trainer aircraft accounted for almost 2/3 of all Class A mishaps (Reference Table 78).

In the period between January 1977 and December 1978, attack/fighter/trainer aircraft had 130 Class A mishaps (Reference Table 79). Of the 130 mishaps, 117 (90%) aircraft were destroyed. AFISC findings on 89 (68%) of the mishaps ranged from "cause undetermined" to using the "preponderance of evidence" with "an element of doubt". The SON concluded that " ... information from a FDR would have been very useful in these 89 events ...".

Study of Designated Aircraft (A10, F15, F16)

The A10, F15 and F16 aircraft were all put in service approximately six (6) years ago. Through calendar year 1980, the Air Force has taken delivery of the following quantity of these aircraft per AFISC data:

A10 - 445
F15 - 563
F16 - 190

TOTAL 1198

During this period from 1975 to 1980, these three (3) aircraft have experienced 56 Class A mishaps; 45 destroyed with an estimated 21 fatalities (Reference Table 80).

TABLE 78. USAF TOTAL CLASS A MISHAPS (6 YEAR REVIEW FROM AFISC)

	75	76	77	78	79	80
• ALL CLASS A MISHAPS	93	87	90	98	94	81
• ALL FATALITIES	281	116	89	89	80	94

TOTALS

CLASS A MISHAPS	543
FATALITIES	660

E-9661

TABLE 79. USAF ATTACK/FIGHTER/TRAINER MISHAP HISTORY (JAN. 1977 TO DEC. 1978) (SOURCE: STATEMENT OF NEED)

	AFISC FINDINGS	NUMBER CLASS A MISHAPS	% TOTAL MISHAPS
(1)	"CAUSE UNDETERMINED"	12	9
(2)	"FAILED PART KNOWN"		
	"UNKNOWN"		
	- FAILURE MODE	34	26
	- CAUSE FACTOR		
(3)	"PREPONDERANCE OF EVIDENCE"		
	"CONTAIN ELEMENT OF DOUBT"	43	32
	TOTAL	89	68%

TOTAL MISHAPS – 130
TOTAL DESTROYED – 117

COMMENT: ". . . INFORMATION FROM A FDR. . . VERY USEFUL IN 89 OF THE 130 EVENTS"

E–9659

TABLE 80. CLASS A MISHAPS DESTROYED (AFISC DATA - PERIOD: CY1975 - CY1980)

AIRCRAFT	CLASS A	DESTROYED	FATALITIES
A – 10	22	21	13
F – 15	25	18	8
F – 16	9	6	0
TOTALS	56	45	21

$\frac{\text{DESTROYED}}{\text{CLASS A}} = 0.8$

E–9682

The attrition rate (A/R), that is the number of aircraft destroyed per 100,000 flight hours, was reviewed based on these statistics, on the following basis:

(1) $\dfrac{\text{Number of A/C Destroyed Most Recent Calendar Year}}{\text{Number of Flight Hours Most Recent Calendar Year}}$

(2) $\dfrac{\text{Total Number of A/C Destroyed in All Calendar Years}}{\text{Total Flight Hours in All Calendar Years}}$

Forecasting the A/R thus becomes an exercise of reviewing:

* Most recent A/R

* The change in A/R from year to year

* The cumulative A/R for that aircraft since service entry.

Although rapid changes in technology make long term comparisons between old and new aircraft difficult, a review was conducted with respect to A/R on one twin engine and one single engine fighter for comparative trends in A/R to apply to the A10, F15, F16 aircraft.

To lend a 15 to 20 year perspective to this summary, data on the F-4 Phantom and the A-7 Corsair are included.

AIRCRAFT	A/R Calendar Year 1980	A/R Cumulative Calendar Year 1980
F-4	5.4	6.5
A-7	7.7	3.3

A10, F15, F16 Attrition Rates

A review of the A10, F15, F16 aircraft shows the expected range of attrition rates (A/R's) is a function of the number of aircraft in inventory, flight hours flown and years of operational service (Reference Tables 81 and 82).

The F15, with 563 in service and with 340,000 flight hours has the lowest cummulative A/R of 5.29. The F16 has the highest cumulative A/R of 16.7 with the shortest operational life, lowest inventory and 1.0% of the flight hours of the F15. A review shows the A10 and F15 starting off with double digit A/R's and then declining.

TABLE 81. ATTRITION RATES - 6 YEAR HISTORY

AIRCRAFT	ITEM	75	76	77	78	79	80	CUMULATIVE
A – 10	D	0	0	2	5	8	6	21
	F	1	4	17	44	87	130	283
	A			12	11	10	5	7.4
F – 15	D	1	0	2	7	5	3	18
	F	4	18	42	69	97	109	339
	A	22	0	5	10	5	3	5.3
F – 16	D	0	0	0	0	2	4	6
	F	.1	.2	.9	1.4	6.5	26.7	36
	A	0	0	0	0	31	15	16.7

D – NUMBER AIRCRAFT DESTROYED

F – FLIGHT HOURS (000)

A – ATTRITION RATE $\frac{\text{AIRCRAFT DESTROYED}}{\text{100K FLIGHT HOURS}}$

E – 9645

TABLE 82. A-10, F-15, F-16 COMPOSITE DATA

(AIRCRAFT DESTROYED, FLIGHT HOURS, INVENTORY, ATTRITION RATES)

		CALENDAR YEARS					
		75	76	77	78	79	80
EACH YEAR	DESTROYED	0	0	2	5	8	6
	INVENTORY	9	27	82	172	300	445
	FLIGHT HOURS (FH)	936	3678	16722	44538	86592	130069
	ATTRITION RATE	-	-	11.98	11.24	9.23	4.61
	FH/A/C/YEAR	104	136	204	259	289	292
CUMULATIVE	DESTROYED	0	0	2	7	15	21
	FLIGHT HRS	936	4614	21336	65874	152466	282535
	ATTRITION RATE	-	-	9.37	10.62	9.83	7.43
EACH YEAR	DESTROYED	1	0	2	7	5	3
	INVENTORY	55	157	279	372	477	563
	FLIGHT HOURS	4541	17803	42369	69023	96947	109304
	ATTRITION RATE	22.02	-	4.72	10.14	5.15	2.74
	FH/A/C/YEAR	83	113	152	186	203	194
CUMULATIVE	DESTROYED	1	1	3	10	15	18
	FLIGHT HOURS	4541	22344	64713	133736	230683	339987
	ATTRITION RATE	22.02	4.47	4.63	7.47	6.5	5.29
EACH YEAR	DESTROYED	0	0	0	0	2	4
	INVENTORY	2	2	6	12	68	190
	FLIGHT HOURS	161	226	856	1402	6527	26745
	ATTRITION RATES	-	-	-	-	30.64	14.95
	FH/A/C/YEAR	80	113	143	117	96	140
CUMULATIVE	DESTROYED	0	0	0	0	2	6
	FLIGHT HOURS	161	387	1243	2645	9172	35917
	ATTRITION RATE	-	-	-	-	21.8	16.7

- SOURCE: AFISC

A forecast of the 1981 attrition rates was calculated based on AFISC estimates of the number of aircraft expected to be destroyed and the planned flight hours to be flown in 1981:

AIRCRAFT	DESTROYED	FLIGHT HOURS	A/R
A10	6	160,926	3.72
F15	5	104,413	4.78
F16	7	50,572	13.79

Attrition Rate Reduction Determination

The basic premise for FDR use is that increased knowledge of mishap causes prevents future mishaps and thus reduce aircraft losses.

All three US military services today are focusing increased attention on FDR use:

* US Army - AIRS Program

* US Navy - FDR Brassboard linked to Laboratory fighter simulator

* US Air Force - CSFDR Study

Additionally the Society of Automotive Engineers (SAE) is now determining FDR requirements for the National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA) for small commercial aircraft through the A-4 sub-committee.

Thus the objective of this summary is to arrive at a number of aircraft that will be saved by using CSFDR's. The determination of this number requires sound judgements made by experienced and trained pilots, accident investigators, safety officers and flight engineers both in the armed services and in industry.

To arrive at a number of aircraft expected to be saved, focus was directed upon two areas where improved cause/factor determination will result in taking corrective action with a high level of confidence thereby saving aircraft. These two areas are:

* Repeat Cause/Factors - Those Class A mishaps with the same cause/factors. As noted previously, the SON makes four (4) references to "repetitive causes".

* Minor Mishaps Related to Class A - Those minor incidents that eventually lead to Class A mishaps such as:

    * Flying outside the flight envelope
    * Overboosting the engine(s)

* Hard landings
* Stalls
* Missed approaches

To accomplish this objective, industry judgement was sought for obvious reasons. The AFISC has reviewed 543 Class A mishpas in the past six (6) years and thousands of lesser mishaps. The airframers, while not reviewing such quantities of events, nevertheless become highly specialized in investigation procedures on any one particular aircraft.

The years of field investigations, mishap reconstruction, debriefing of pilots, etc. make these personnel well qualified to render experienced estimates on the following factors.

Judgement Factors Requested

In asking the following questions related to repeat causes and related minor mishaps, two ground rules were established for the respondents:

1. Consider Class A mishaps only.

2. Exclude those mishaps caused by human factors of a personal nature since these types of causes cannot be remedied by additional training or procedural changes.

The following questions were posed based on the premise

Cause Identification + Fix (Corrective Action) = Saved Aircraft

"In your best judgement:

1. What percent of all Class A mishaps have repeat causes?

2. What percent of all minor mishaps are related to (eventually becoming) Class A mishaps?

3. What percent of those repeat cause Class A mishaps can be fixed?

4. What percent of those related minor mishaps can be fixed?

The range of responses were as follows:

ITEM	% OCCURRENCE		% FIX	
	LOW	HIGH	LOW	HIGH
1. Repeat Cause/Factor	10%	40%	25%	50%
2. Related Minor Mishaps	2%	10%	0%	50%

Improved Cause/Factor Determination With CSFDR

The SON mishap data states that out of 130 events, 89 (68%) had cause/factor determinations that ranged from "unknown" to "uncertain". On the premise had a CSFDR been installed on those 130 aircraft, the cause factor determination for mishaps would have been improved. With the causes now known and a fix implemented, future mishaps with similar causes will be prevented, and aircraft saved.

As an example, we applied the lowest industry judgement factors (improvement rates of 10% on repeat causes and 2% on minor mishaps) to these 89 mishaps (reference Table 83) and the number of known mishap causes is improved by 10.7. This 10.7 improvement is normalized to 8.2 per 100 Class A mishaps.

To arrive at the number of candidate aircraft saved, the 8.2 estimate is derated by the following factors:

* Undestroyed Aircraft - According to Hamilton Standard's analysis (reference Section 2.3), of 368 mishaps, only 57% of all Class A mishaps represent destroyed aircraft.

* CSFDR Survival Rate - based on survivability studies for mishaps (again reference Section 2.3), the CSFDR will survive 50% of all "smoking hole mishaps in which 20% of all Class A mishaps are involved thus resulting in a 90% survival rate for all Class A mishaps [100% - (20%X50%) = 90%].

* Fix Rate Estimate - Having deducted destroyed aircraft and those events where the CSFDR does not survive eliminates those mishaps which, in industry's judgement, can be fixed. The example uses the lowest rate of 25%.

The fully derated improvement factor resulting in saved aircraft becomes: (Table 83.).

8.2	X	57%	X	90%	X	25% =	1.05
(Candidate A/C Saved)		(A/C Destroyed) (Class A)		(CSFDR Survival Rate)		(Fix Rate)	(A/C Saved Per 100 Class A Mishaps)

The number of A-10's estimated to be saved is computed by applying the improvement rate to the total number of A-10 Class A mishaps.

296	X	.0105	X =	3.1
(Class A Mishaps)		(A/C Saved Rate Per 100 Mishaps)		(Number Estimated A-10's Saved)

TABLE 83. IMPROVED C/F DETERMINATION WITH FDR (130 CLASS A EVENTS)

	AFISC FINDINGS	(SON) NUMBER OF CLASS A	INDUSTRY JUDGEMENT FACTORS REPEAT CAUSES	MINOR MISHAPS	IMPROVED NUMBER OF MISHAPS WITH C/F DETERMINED
(1)	● "CAUSE UNDETERMINED"	12			
(2)	● "FAILED PART KNOWN" ● "FLR MODE UNKNOWN" ● "C/F UNKNOWN"	34			
(3)	● "PREPONDERANCE OF EVIDENCE" ● "ELEMENT OF DOUBT"	43	10%	2 %	
		89	8.9	1.8	10.7

NORMALIZED $\frac{\text{10.7 IMPROVED}}{\text{130 CLASS A}}$ = 8.2/100 MISHAPS

E-9500

In addition, partially destroyed aircraft are arrived at by excluding the 169 totally destroyed aircraft, and applying the CSFDR improvement rate, fix rate and assuming the CSFDR will be intact in this type of mishap.

[296	-	169]	X	.082	X	.25 =
(Class A Mishaps)		(A-10 Destroyed)		(CSFDR Imp. Rate)		(Fix Rate)

2.7 (Estimated number of partially destroyed A-10 saved)

Of course the aircraft save rate is sensitive to the industry judgement factors. Table 84 shows the forecasted number of destroyed A-10's, the percentage of unknown/uncertain to known mishap causes, the improved number of mishaps with unknown causes, the CSFDR survival rate and a range of aircraft saved indexed to the industry judgement factors. We have indicated the low range (3) and mid-range (11) estimates on totally destroyed aircraft only.

Payback Analysis (A10) - 1980 Economy

Using the A10 aircraft Life Cycle Cost (LCC) analysis of Section 5.1, the payback analysis used the following asumptions:

* Planned buy of 739 aircraft.
* 20 year service life ending 2001.
* CSFDR installation to be completed by 1985 on 690 aircraft.
* Attrition rate of 3.0 per 100,000 flight hours.
* Forecast of 169 totally destroyed aircraft. (See Table 85.).
* Destroyed aircraft to Class A mishaps rate of .57.
* Fatalities to destroyed aircraft of .44. (See Table 86.).
* A-10 buy price: $5.2 million.
* Partially destroyed Class A mishap average cost $2.7 million.

$$\frac{\text{(Class A minimum Value +A-10 Price)}}{2} = \frac{\$.2M + \$5.2M}{2} = \$2.7M$$

* Aircrew replacement cost: $.26 million.
* All costs are in 1980 economy.

TABLE 84. AIRCRAFT SAVE RATES - A-10

CAUSE/ FACTOR DETER	DESTROYED FORECAST	(R)% (MM)%	IMPROVED NUMBER OF CAUSE /FACTOR DETERMINATIONS – INDUSTRY JUDGEMENTS 10 2	20 4	25 6	30 8	40 10
● UNKNOWN/ UNCERTAIN	115 (68%)		101	87	79	71	57
● KNOWN	54 (32%)		68	82	90	98	112
	169 (100%)						
● IMPROVED NUMBER OF MISHAPS WITH KNOWN CAUSES			14	28	36	44	58
● NUMBER OF MISHAPS WITH CSFDR INTACT (90%)			13	25	32	40	52
● FIX RATES INDUSTRY JUDGEMENTS		25%	$\boxed{3}$*	6	8	10	13
		30%	4	8	10	12	16
		35%	5	9	$\boxed{11}$**	14	18
RANGE OF AIRCRAFT SAVED		40%	5	10	13	16	21
		50%	7	13	16	20	26

**MID RANGE
* LOW RANGE

E–9694

TABLE 85. A-10 LIFE HISTORY DATA (ESTIMATED)

Year	Plan	Destroyed		Inventory	Flight Hours (In Thousands)	
		Per Year	Cumulative	(Less Attrition)	Per Year	Cumulative
1975	9	0	0	9	0	0
1976	27	0	0	27	3.7	4.6
1977	82	2	2	80	16.7	21.3
1978	172	5	7	165	44.5	65.8
1979	300	8	15	285	86.5	152.3
1980	445	6	21	424	130.0	283.0
1981	594	6	27	567	161.0	444.0
1982	677	6	33	644	241.5	685.0
1983	739	7	40	699	262.0	947.0
1984		8	48	691	259.0	1,206.0
1985		8	56	683	256.0	1,460.0
1986		8	64	675	253.0	1,720.0
1987		8	72	667	250.0	1,970.0
1988		8	80	659	247.0	2,200.0
1989		7	87	652	244.0	2,500.0
1990		7	94	645	242.0	2,700.0
1991		7	101	638	239.0	2,900.0
1992		7	108	631	237.0	3,200.0
1993		7	115	624	234.0	3,400.0
1994		7	122	617	231.0	3,600.0
1995		7	129	610	229.0	3,900.0
1996		7	136	603	226.0	4,100.0
1997		7	143	596	224.0	4,300.0
1998		7	150	589	221.0	4,500.0
1999		7	157	582	218.0	4,800.0
2000		6	163	576	216.0	5,000.0
2001		6	169	570	214.0	5,200.0

NOTES: 1. Actual attrition rates used prior to 1981. Attrition rate of 3.0 per 100,000 flight hours from 1981 on.
2. Assume 375 flight hours per A/C per year
3. CSFDR installation started in 1983.
4. CSFDR installed fleetwide in 1985.

TABLE 86. CSFDR STUDY DATA - 1975 to 1980: FATALITIES TO DESTROYED AIRCRAFT RATE

DATA SOURCE	NUMBER CLASS A MISHAPS	NUMBER AIRCRAFT DESTROYED	NUMBER OF FATALITIES	FATALITIES / DESTROYED AIRCRAFT
A – 10	22	21	13	.62
F – 15	25	18	8	.44
F – 16	9	6	0	0
(1) TOTALS	56	45	21	.47
STATEMENT OF NEED	130	117	51	(2) $\boxed{44}$

(1) AFISC

(2) USED IN PAYBACK ANALYSIS

E–9693

* Lowest industry judgement factors used in determining the improved number of known mishap causes:

Repeat Causes	-	10%
Minor Mishaps	-	2%
Fix Rate	-	25%

Based on the above assumptions, in the twenty (20) year service life of the A-10 approximately three (3) totally destroyed aircraft and two (2) partially destroyed aircraft are estimated to be saved:

The cost savings which result would be $23,500,000.

* Aircraft

  Totally destroyed: 3.12 aircraft X $5.2M/Aircraft = $16.1M.

  Partially destroyed: 1.81 aircraft X $2.7M/Destroyed Aircraft = $7.0M

* Aircrew: 3.12 aircraft X .44 Fatals/Destroyed Aircraft X $2.6M/Aircraft = $.4M.

Return on Investment

The LCC analysis puts the fully installed CSFDR cost at $18.3 million. Applying the gross savings against the investment, the net savings are $5.2 million.

It should be noted that there are several factors which could have a very positive effect on the estimated savings presented herein.

* The judgement factors used in the analysis represent the lowest estimated by industry, 10% on repeat mishaps and 2% on related minor mishaps and 25% on possibility of corrective action fix. The A-10 cost savings range: From $23.5M at the low to $84.9M mid-range. (Table 87) (Note: The AFISC estimates 100% of mishaps with known causes can be fixed.

* The A10 cost factors for CSFDR's remain essentially the same for the F15 and F16, however, replacement costs of these aircraft is substantially higher. It is therefore assumed, that, although attrition rates for the F15 and F16 are lower, the savings will be equal to or greater than for the A10. Table 88 shows the gross dollar savings for the F-15 and F-16 would afford substantial paybacks to the Air Force.

* The ratio of destroyed (Class A mishaps) aircraft from the 368 analyzed by Hamilton Standard (Section 2.3) may be conservative. AFISC computer data shows 57% of all Class A mishaps are destroyed. Other AFISC data indicates higher ratios.

TABLE 87. A-10 DOLLAR COST SAVINGS (1980 ECONOMY)

- GROSS SAVINGS INDEXED TO INDUSTRY JUDGEMENT FACTORS

FIX RATES %					
(R)%	10	20	25	30	40
(MM)%	2	4	6	8	10
25	$\boxed{23.5}$ *	47.0	60.7	74.4	97.9
30	28.2	56.4	72.8	89.2	117.4
35	32.9	65.8	$\boxed{84.9}$ **	104.1	137.0
40	37.6	75.2	97.1	119.0	156.6
50	47.0	93.9	121.3	148.7	195.7

(INCLUDES COSTS OF TOTALLY AND PARTIALLY DESTROYED AIRCRAFT AND AIRCREW REPLACEMENT)

* LOW RANGE
** MID RANGE

E-9703

TABLE 88. COST SAVINGS - F-15 & F-16

ASSUMPTIONS IDENTICAL TO A–10 EXCEPT

	F–15	F–16
● UNIT COST	$15M	$10M
● PARTIAL DESTROYED COST	7.6M	$5.1M
● FLEET SIZE (PLANNED BUY)	(A–10) SIZE	1380

F – 15 $ SAVINGS

FIX RATES	IMPROVED C/D DETER 10 / 2	IMPROVED C/D DETER 25 / 6
25	66.6	
35		240.8

F – 16 $ SAVINGS

FIX RATES	IMPROVED C/F DETER. 10 / 2	IMPROVED C/F DETER. 25 / 6
25	62.3	
35		225.5

* SON data reveals that 117 (or 90%) of 130 Class A events resulted in destroyed aircraft (See Table 79.).

* Composite data on A-10, F-15 and F-16 (Table 80) shows that 45 (or 80%) of 56 Class A mishaps resulted in destroyed aircraft.

* The LCC Analysis indicates that application costs when shared over three (3) aircraft programs (A-10, F-15, F-16) are reduced by 50%. These discounted design and development (non-recurring) costs would be applied to this A-10 payback estimate. (Note: This ignores the operating and support costs of a common logistics unit, which could afford additional cost savings).

* The AFISC estimate of $260,000 for training, overhead and benefits appears to be conservative. Several industry members (and newspapers) have estimated costs as high as $1.0M per pilot. These costs would be higher for (2) seat aircraft.

A review of the above factors suggests that equipping all three aircraft (A-10 F-15 and F-16) with CSFDRs that significant payback ratios can be obtained.

Additional Benefits

Although the following additional benefits are very important, a cost savings has not been assigned to them. These topics should be carefully considered not only from the economics viewpoint, but also how they add to mission effectiveness and the general facilities of the Air Force.

* Investigation Benefits - Improved investigation procedures:

  * CSFDR will yield primary direction to the investigation process.

  * Reduction in investigation man hours.

  * Increased accuracy of cause/factor determination.

  * Increased level of confidence in resultant aircraft modifications.

  * Aids determination of subtle cause/factors of a mishap by inputing data into flight simulation.

  * Reduction in time consuming and costly salvage/recovery operations in oceans and mountainous terrain.

* Training Benefits

  * Provide comprehensive cockpit scenario for normal flights/sorties in addition to mishaps.

  * Provides data for improved simulator training.

* Provide a valuable debriefing tool for pilot instructor and student - instant replay possible following flight training.

* More effective modifications in flight and emergency procedures.

* Improved Mission Effectiveness

  * Reduce fleet groundings by speeding up cause/factor identification and providing timely fix.

  * Decrease possibility of repeat mishaps while awaiting cause findings.

  * Reduce unnecessary modification by increasing confidence level of cause/factor determination.

  * Improve maintenance by using CSFDR as an assist in inspection procedures.

Summary

It should be emphasized that the payback estimate given, considered the most conservative values of the following factors:

* Lowest cost aircraft of three considered: A-10 at $5.2M

* Lowest expert opinion improvement estimates

  - Repeat causes: 10% to 40% - 10% used
  - Related minor mishaps: 2% to 10% - 2% used
  - Fix rates: up to 50% - 25% used

* Hamilton Standard analysis of AFISC computer data of aircraft destroyed to Class A mishap rate of .57 (It should be noted that the SON mishap data rate was .90 and the 6 year review of the A-10, F-15 and F-16 composite rate was .80.)

* The $2.7M cost used is derived from the lowest cost aircraft.

* Aircrew replacement cost of $.26M includes cost of recruitment, training, entitlements and benefits.

* CSFDR survival rate .90 (Source: Hamilton Standard analysis).

* Additional benefits outlined, but with no dollar savings assigned.

Final Observations and Recommendations

Table 87 indicates that substantial gross savings are possible on the F-15 and F-16 as a function of their higher unit cost by using essentially the same payback assumptions of the A-10 model. This brief payback outline indicates large potential savings:

- From equipping all three fleets (A-10, F-15, F-16) with CSFDRs.

In addition, the following was ignored:

- Favorable cost sharing effects from this combined effort in reducing non-recurring costs.

- Additional Operating and Support cost savings resulting from a common logistics unit.

6.0 CONCLUSIONS

The following conclusions are given based on the requirements and evaluation study as reported herein.

(1) A single low cost, light weight, solid state CSFDR design can be executed responsive to Air Force needs for F15, F16 and A10 application in the 1982 time frame. The design can be applied economically to all fighter, attack and trainer aircraft in Air Force inventory.

(2) The baseline CSFDR defined herein has direct application to a broad range of military aircraft throughout the tri-services. All small fixed wing and rotary wing aircraft could benefit from a single standard design without a significant design penalty. Large multiengined aircraft with two or more crew members have unique requirements that economically preclude commonality with the smaller aircraft studied herein.

(3) Maintenance monitoring functions can benefit from an installed CSFDR as defined herein by taking advantage of the CSFDR's signal conditioning and non-volatile data memory. Integration of these functions with the CSFDR will reduce maintenance monitoring costs significantly without significant cost penalty to the CSFDR.

(4) It is estimated that a crash survivable data memory module design can be executed that will provide data for mishap investigation with a 90% or greater probability of success for severe Class A accidents.

(5) The life cycle cost analysis versus the estimated attrition rate reduction indicates a two to one cost payback taking the most conservative analysis approach and factors obtained from expert opinion. the cost payback improves as the number and type of aircraft included increases.

7.0 RECOMMENDATIONS

The following recommendations are made:

(1) A development program should be initially aimed at production installation of a CSFDR based on current proven technology.

(2) Effort should be initiated for preparation of a tri-services specification for CSFDR application to selected aircraft where requirements are determined to be common. This effort could coincide with or be a part of recommendation (1).

(3) A separate Requirements Study should be initiated for Air Force transports and bombers similar to the effort reported herein.

LIST OF ABBREVIATIONS

A	Angstroms
A/B	Afterburner
AC	Alternating Current
A/C	Aircraft
A/D	Analog to Digital
ADC	Air Data Computer
AFISC	Air Force Inspection and Safety Center
AIRS	Accident Information Retrieval System
AOA	Angle of Attack
APU	Auxiliary Power Unit
A/R	Attrition Rate
A/S	Airspeed
ASIPS	Aircraft Structural Integrity Performance System
Ave or Avg	Average
BAMS	Binary Angular Measurement System
BIT	Built-In-Test
BORAM	Block Oriented Random Access Memory
BTU or Q	Heat in British Thermal Units
CADC	Central or Control Air Data Computer
CAS	Control Augmentation System
CLP	Caution Light Panel
CMOS	Complimentary Metal Oxide Semiconductor
CSFDR	Crash Survivable Flight Data Recorder
CDRL	Contract Data Requirements List
D/A	Digital to Analog
DC	Direct Current
DEG C or °C	Degrees Celsius
DEG F or °F	Degrees Fahrenheit
DEG R or °R	Degrees Rankine
DEMOD	Demodulator
EAROM	Electrically Alterable Read Only Memory
ECP	Engineering Change Proposal
EDS	Engine Diagnostic System
EEC	Electronic Engine Control
EEPROM or E^2PROM	Electrically Eraseable Programmable Read Only Memory
EGT	Exhaust Gas Temperature
EO	Output Voltage
EX	Excitation Voltage
FAA	Federal Aviation Administration
FCC	Flight Control Computer
FCS	Fire Control System
FDR	Flight Data Recorder
FMU	Field Maintenance Unit
FREQ of f	Frequency
FS	Fuselage Station
FT	Feet
FTIT	Fan Turbine Inlet Temperature
G	Acceleration

LIST OF ABBREVIATIONS (Continued)

GND	Ground
GRU	Ground Readout Unit
GSE	Ground Support Equipment
HARS	Horizontal Attitude Reference System
HR(s)	Hours(s)
HZ	Hertz
ID	Identification
INS	Inertial Navigation System
I/O	Input/Output
K	Thousand
KTS	Knots (Nautical Miles Per Hour)
LB(s)	Pound(s)
LCC	Life Cycle Cost
LEF	Leading Edge Flap
LRU	Line Replaceable Unit
LSI	Large Scale Integration
LVDT	Linear Voltage Differential Transformer
MAX	Maximum
MEG	One Million
MILLI or M	One per Thousand
MIN	Minimum
MMH	Maintenance Man Hours
MNOS	Metal Nitride Oxide Semiconductor
MTBF	Mean Time Between Failure
MTBR	Mean Time Between Repairs
MUX	Multiplexer
MICRO or	One Per Million
NA	Not Applicable
N_C or N_2	Compressor Rotational Speed
N_F or N_1	Fan Rotational Speed
NTSB	National Transportation Safety Board
OAT	Outside Air Temperature
PARA	Parameter
PC	Printed Circuit
PLA	Power Lever Angle
PROM	Programmable Read Only Memory
PSI (D)	Pounds Per Square Inch Absolute (Differential)
RAD	Radians
RAM	Random Access Memory
ROM	Read Only Memory
RPM	Revolutions Per Minute
RS232	Electronics Industries Association Data Interface Standard
SAE	Society of Automotive Engineers
SAS	Stability Augmentation System
SB	Speed Brakes
SCU	Signal Conditioner Unit
SEC	Second

LIST OF ABBREVIATIONS (Continued)

T	Time
TBD	To Be Defined
TEF	Trailing Edge Flap
TEMP	Temperature
TO/LDG	Takeoff and Landing
TSO	Technical Standing Order
TTL or T^2L	Transistor Transistor Logic
USAF	United States Air Force
VAC	Volts-Alternating Current
VDC	Volts-Direct Current
VPK	Volts-Peak
VR	Voltage Ratio
VRMS	Voltage-Root Mean Square
WL	Water Line

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